November 4, 2015

Dr. Patricia M. Dehmer
Acting Director, Office of Science
Department of Energy

Dear Director Dehmer,

I am writing in my capacity as Chair of the Advisory Committee for the Division of Biological and Environmental Research in response to your charge letter to the committee dated September 23, 2014. This letter specifically requested that the committee examine the needs, requirements, suitability and specifications of Integrated Field Laboratories (IFL), building off of the recommendations made by the committee in the 2013 BERAC report "BER Virtual Laboratory: Innovative Framework for Biological and Environmental Grand Challenges". The BERAC was delighted to respond to the charge in light of the potential for IFLs to substantially advance BER science.

Your letter specifically requested that BERAC address

- Identify candidate geographic regions that are poorly understood with respect to earth system predictability, e.g., under-studied, under-sampled, climatically sensitive, and/or a source of significant prediction uncertainty;
- Identify major cross-cutting gaps in BER sciences that limit our understanding of the predictability of earth science across numerous geographic regions;
- Exploit unique BER assets, e.g., ARM, JGI, EMSL, and other major field activities, where possible;
- Exploit science capabilities of both CESD and BSSD, where relevant;
- Provide opportunities for collaborations involving other federal agencies; and/or
- Exploit emerging scientific discoveries and advanced technologies from other disciplines, e.g., computational, observational, sensing, visualization.

Your request was first discussed by the committee during its October, 2014 meeting. This discussion was broad but settled on five possible environments best suited to address important scientific questions: urban-to-wildland gradients, arid lands, agricultural, coastal and mountains. However, among these, the consensus was that an urban focus was where the need was the greatest and where establishment of IFLs would have the biggest impact. This finding led to the hosting of a workshop held Jan. 29-30, 2015, leading to the release of a draft report (attached to this letter). This report was discussed at the Feb. 2015 BERAC meeting and was approved. However, the BERAC felt the need to more broadly address the requests in your letter by providing information on the other four environments identified. In order to provide this information, four subcommittees were developed involving both BERAC and non-BERAC members that led to four short white papers addressing the arid, agricultural, coastal and mountain environments (also attached). These collective efforts led to the drafting of this letter, which was circulated among all BERAC members, discussed at our October, 2015 meeting, revised, unanimously approved and now forwarded to you.

In line with IFL concepts described in the Virtual Laboratory Report, which called for the need to study interactions and feedbacks occurring along significant lateral and vertical gradients, **BERAC envisioned the IFLs as focusing on gradients** between two or more end-member environmental systems. In particular, BERAC recommends focusing on gradients from an urban environment to one or more of the other environmental systems (e.g., urban to coastal, arid, agricultural, or mountain).

The attached white papers lay out the specific rationales for each environment. In brief,

Coastal: Approximately 50% of the US population lives in coastal counties with the coastal population increasing by 1 million per year. The coast consists of a variety of environments, all of which are heavily impacted by human activity. Because of the extreme importance of human population density and economic activity in coastal systems, as well as their unique ecological functioning, integrated field campaigns might take advantage of two different kinds of transect-based studies. One, extending from upland watershed boundaries through the coastal region itself and into coastal marine systems and, two, going from regions more to less perturbed by human activity and land use, while going through ecologically similar landscapes. Such transects could in principle yield information on the resilience and robustness of these coupled human-natural systems.

Arid lands: More than half of the continental United States qualifies as arid or semi-arid, spanning from the Central to Southwestern United States. Arid regions are also the parts of the United States undergoing the most rapid land transitions and where population growth will continue to accelerate urban expansion over the next 50 years. These regions are subject to large inter-annual, precipitation variations and, thus, the potential roles of carbon, water, and energy cycles, key issues of an IFL, are of paramount interest in these regions. It is important to consider the concept of an arid IFL in the context of a gradient, tethered in an urban location at one end and extending to the natural arid/semiarid ecosystems that supply essential resources to cities at the other end.

Mountain: About 60 – 90% of water resources originate from mountains worldwide and there is strong evidence that these resources are being threatened by global warming. By nature of the topography and river networks that connect mountains with the valleys and plains, mountains are natural focal points of environmental gradients, and their influence can extend much beyond the local terrain. Mountain water resources are additionally vital to hydropower energy production, and water dynamics through mountainous river basins mediate carbon, nutrient and metal transport. Current earth system models have limited ability to simulate atmospheric, hydrologic, cryospheric, ecological and biological processes in mountains, because the large spatial heterogeneity is not adequately resolved, and the complex processes, their interactions, and their cascading effects are not well understood or represented in models. An objective of an IFL would be to improve model predictive capability, including both feedbacks to climate and how mountainous watersheds respond to disturbances, including floods, droughts, and shifts in snowmelt. A mountainous river basin IFL could include a gradient from a mountain region to a downgradient urbanized region, or from the summit to coastal regions.

Agricultural: Over 50% of land in the conterminous U.S. is under agricultural management, making agriculture one of the dominant human influences on the American landscape. Understanding the footprint of agriculture on the earth system is thus a crucial piece for understanding human impacts in general, especially as population growth and growing global affluence accelerates the demand for food and as the critical need for clean energy accelerates demands for bioenergy. An agricultural IFL would be especially relevant to understanding climate change impacts and adaptation in these systems, as well as mitigation – through both sustainable bioenergy development and the emerging potential for biomass carbon capture and storage. An IFL could focus on an urban region moving outward to include nearby agricultural lands directly impacted by suburbanization, ultimately reaching truly rural environments.

Urban: While BER research has historically focused on the carbon, water, and energy cycles of natural ecosystems and how these processes impact our climate system, we lack an equivalent understanding of coupled natural-human systems, such as urban and urbanizing systems. Given the strong BERAC support for establishment of IFLs focused on urban environments, I will use this environmental setting to address the issues raised in your letter specifically. In each case, similar recommendations apply to each of the 5 environs examined (see attachments).

A key recommendation of the BERAC 2013 report was that "… IFLs would be located in environments representative of large, rapidly changing regions or areas strategically important for the bioeconomy." This led BERAC to focus on coupled natural-human systems, including urbanizing regions, as greatly understudied ecosystems where

- Rapid land-use changes were occurring that intensified water, carbon, and nutrient cycles.
- The role of changing energy sources and the nature of future urban development could lead to unpredictable future emissions scenarios and, therefore, increased uncertainty about the drivers of climate change.
- The integrated bi-directional connectivities between natural and human-built systems and the drivers of change are not well understood and could lead to future surprises not currently predictable based on existing models.
- The impacts of current and future intensification of energy, carbon, and water cycles could lead to higher uncertainties in predictions of regional and global models.

Currently, over one-half of the world's population reside in urban areas and this proportion is projected to rise to two-thirds by the middle of the 21st century. While urban areas currently represent a small percentage of the terrestrial surface, they are the primary user of energy and generate more than 70% of the global greenhouse emissions. The uncertainties in how the carbon, water, and energy fluxes of urban systems, natural systems, and their connectivities operate now and into the future form the rationale for developing an IFL. If we are going to create sustainable cities and sustainable coupled natural-human systems, then we need to understand these processes in the same depth that we seek for natural systems. IFLs focusing on urban systems and coupled natural-human systems could also be leadership opportunities for the DOE, where partnerships would emerge with other federal agencies, the private sector, and municipalities, making sure that our science investments also had a significant and immediate return for society.

Cities have the potential to serve as "first responders" for climate action to reduce emissions. However, our current estimates of urban-scale carbon fluxes are highly uncertain (50–100% error) making it nearly impossible to assess progress towards emissions reduction goals or the efficacy of urban mitigation policies. Against this backdrop of uncertainty, climate policy is emerging at the local and urban scales. Cities are critical participants in the implementation of climate policy because the urban landscape is where the majority of industry operates, consumers live, and power is consumed. It is at the municipal-to-regional scales where knowledge about local mitigation options, costs, and opportunities is needed most.

Key science and/or technological questions: The driving force for creating an IFL must be based on critical science questions of sufficient size and scale that a geographically distributed network is required to answer the science questions and to inform the wide spectrum of policy makers and stakeholders. Two types of science question drive the need for an IFL. The first type includes fundamental questions about the structure and function of coupled natural-human systems, including theory and observations that lead to a basic knowledge of how these systems work—i.e., mechanistic questions. For example, what are the component parts of the system, how do they function and interact, what are the relevant scales of interaction and the relative importance of biophysical, societal, contextual, cross-scale, and other drivers? What are the linkages between the human dominated components of systems and the environment that provisions and sustains them? The second type of question focuses on dynamics and trajectories: How are things changing? How can decision-making alter or bend the flows of carbon, energy, and water? How do altered trajectories feedback on decision-making?

A focus on these two types of questions will provide answers to pressing Grand Challenge questions; such as,

- ✓ What are the energy, water, and GHG flows of urban systems in a changing environment?
- ✓ What are the drivers, controls, and feedbacks between the Earth System and humans systems from the global scale to finer grain scales more immediately relevant to the human experience?
- ✓ How do microbial communities associated with different habitats affect the transformation and transport of pollutants and fluxes of energy and GHGs in soil, subsurface, aquatic, and other urban environments?
- ✓ How do gene by environment (G x E) interactions affect the productivity of plants and their effects on microclimate and the abatement of GHGs and other pollutants in urban environments?

- ✓ How can this knowledge inform Earth System communities?
- ✓ How can this information be used to inform stakeholders about ways to mitigate environmental impacts and lead to more resilient and sustainable urban systems?

Answering these questions aligns well with DOE’s mission to ensure America’s security and prosperity by addressing its energy and environmental challenges and with BER’s mission to advance world-class biological and environmental research in support of DOE’s mission.

Modeling: While an IFL is conceived primarily as the observational component of a Virtual Laboratory, modeling will be an essential element to ensure the IFL meets its objectives. Models encapsulate our knowledge of individual components and their interactions. For urban systems, the interaction aspects are most formidable as they represent the intersection of human and natural systems, and carbon, energy, and water cycles that span a significant range of scales. Models provide a framework for integrating observations to generate comprehensive databases for knowledge discovery.

While modeling supports the IFL in achieving its science goals, the IFL must also be designed to support the data needs for modeling. Symbiotic model – data integration is thus essential to address the key science questions of the IFL. Underpinning the emphasis on predictive modeling is recognition that the IFL concept must include a focus on new computational technology and software frameworks, integration of data collection, transfer, storage, analysis, and visualization, and connections to new generations of the nation’s science and technology workforce. The IFL should play an important role as an incubator for new instrumentation and measurement technology. Novel instrumentation, sensors and sensor networks will be particularly critical in the highly heterogeneous urban landscape.

Opportunities for collaboration: While there are now a few scientific programs with urban components (e.g. LTER, NOAA, NIST), they lack cross-site integration. Network concepts are in their infancy and DOE led and integrated IFLs would represent a significant advancement in coupling human activities and earth system science. The IFLs should be designed in such a way that there are expanded opportunities for sharing data and observations. A network of IFL’s examining gradients from urban to other environments would be innovative and is strongly recommended by BERAC.

An urban-tethered IFL should have a complement of observations, models and integrated analyses, and be enabled by an end-to-end data and information management system with high-end computational capabilities. The interdisciplinary nature of IFL science questions requires multi-layered (i.e. phenomena, time, space, etc.) data sets. This multidimensional aspect of data sets poses a major challenge and opportunity for DOE to work closely with other agencies (e.g. NASA, NOAA, EPA, NSF, etc.). A combination of large-scale data sets and integrated human-Earth system models require access to DOE sponsored high-end computational capabilities.

We expect the National Laboratories to play important roles in the development of IFLs with an urban focus. The Laboratories have the continuity and the infrastructure necessary to equip, maintain, and manage the data from IFLs for the time that such field campaigns should be maintained, which we feel is at least a decade. The National Labs have played similarly crucial roles in the development and maintenance of other DOE field programs, or large experimental programs, such as NGEE-Arctic and Tropics, Ameriflux, Biofuels Research Centers, ARM, and EMSL. However, the specific sites or transects chosen must be competed for on the basis of the degree to which they are suitable for addressing important scientific questions.

Challenges to the design of an urban IFL: There are multiple challenges inherent in proposing a field laboratory in urban areas: phasing of implementation, data types and interoperability, siting of instrumentation, scale of measurement, identification of parameter measurements that don't exist or perform at the levels needed, involvement of stakeholders, integration with existing federal observation systems, quality control, and education and outreach. Therefore, we advocate a model for implementing IFLs that occurs in phases and, where possible, utilizes existing capabilities and investments. Major field observation systems or experiments often are conceived without considering the conceptual frameworks, interoperability, and modeling from the start, yet these elements are essential for a next-generation observatory. The gaps in understanding revealed by modeling systems from the outset will ensure efficiency in design of IFL components and variables to be measured. It also is critical that a data handling structure be in place, preferably one that can communicate with other observatories and with a variety of data types (e.g., spatial, economic, social, etc.). The diversity of information to be gathered demands early consideration of how that data can be made widely available (interoperability).

Siting urban IFLs in and around cities will present unique challenges. For example, instrumenting the IFL will have to recognize privacy concerns. Capturing the spatial heterogeneity will most likely require engaging multiple types of land owners. Indeed, tremendous spatial heterogeneity at multiple scales is a hallmark of urban regions and the heterogeneity in biophysical features is mirrored by heterogeneity in existing infrastructure and social structure. Past studies have mostly avoided urban areas where the mix of anthropogenic and natural fluxes is complex and difficult to isolate observationally. However, these hurdles should be surmountable with strong DOE leadership. Given a focus on local-to-regional drivers and feedbacks in climate, energy, water, and land use, early involvement of local and regional stakeholders will be essential to success of an IFL. These stakeholders include local and regional policymakers, managers, and planners; members of the business community, and various publics, in addition to academic and federal researchers and modelers. The IFL can draw from the rich experience of the two NSF urban LTERs in figuring out how to engage and take advantage of the experiences and perspectives of their stakeholders.

Open data access, interoperability, and integration of sensor-derived data with models in real time, such as might be envisioned for the urban IFL, are currently in the "culture" of only a small segment of the scientific community. Therefore, there is a real need to integrate an educational and social component in the IFL, to train the next generation of modelers and analysts of massive quantities of highly heterogeneous information.

Governance and coordination: An IFL will involve the 'hardware' of data collection and analysis but will be more than this, as a platform for model–data integration, data sharing and access, and communication and interaction with other observational activities. The governance of such a network thus will entail the goals of IFL oversight, ensuring interoperability, and coordination with other DOE resources and other federal agencies. A consortium (including all collaborators and stakeholders) model for governance of the IFL seems most appropriate to achieving these goals. The consortium might be governed by a board that includes the lead scientists of each IFL site, a technical group that oversees interoperability and data quality control, and an interagency group. It will be critical to select proven leaders and assemble a competent team to insure the success of the IFL.

Competing the individual IFL sites through a formal solicitation process would allow the best ideas to emerge but might make integration more challenging; an alternative would be to run a pre-proposal competition, and once finalists are selected, impose some coordination on the incipient network.

DOE Leadership is Critical: Urban ecosystems have been receiving growing attention from many federal agencies as a location for major land cover and land use change impacts, as a dominant and growing source of greenhouse gas emissions, and as a unique ecological and biogeochemical system. Key federal agencies currently supporting related research in the urban sphere include NSF, NOAA, NASA, and NIST. However, none of the programs approaches an integration, scale, and connectivity as envisioned for an IFL. There are clear needs for coupling common urban science research activities that could lead to stronger interactions and greater integration among federally funded urban research at these federal agencies.

Hence, there is a clear opportunity for DOE leadership. Few federal agencies have an organizational structure and history of long-term commitment to the infrastructure and research necessary to address ecological field projects. In many ways, the DOE is uniquely positioned with AmeriFlux, ARM, EMSL, and NGEEs, representing examples of long term commitments that lead to advances in our understanding of the earth system and its components. The DOE is well positioned to provide leadership for development of IFLs and to coordinate with other agencies.

I hope that the above discussion properly summarizes the findings of the collective BERAC activities and addresses the specific questions raised in your original charge letter. Additional details can be found in the accompanying workshop and white papers.

In summary, the key, BERAC recommendations are:

- IFLs should be located in environments representative of large, rapidly changing regions or areas strategically important for the bioeconomy. The BERAC consensus is that coupled natural-human systems, including urbanizing regions, are greatly understudied ecosystems where research can have the greatest impact.

- BERAC envisions the IFLs as focusing on gradients between end-member systems. In particular, BERAC recommends focusing on gradients from an urban setting to one or more of the other focus regions (e.g., urban to coastal, arid, agricultural, and/or mountain).
- Multiple IFLs are envisioned and thought necessary to address pressing questions which have regional contexts (see above and attached reports). Each should be competed with broad input inclusion of stakeholders, national laboratories, and universities.

Sincerely,

Gary Stacey, Ph.D.
Chair, BERAC

An Agricultural IFL

Over 50% of land in the conterminous U.S. is under agricultural management, making agriculture one of the dominant human influences on the American landscape. Globally, the 5 billion ha under agricultural management exceeds the area covered by forest and woodlands. Understanding the footprint of agriculture on the earth system is thus a crucial piece for understanding human impacts in general, especially as population growth and growing global affluence accelerates the demand for food and as the critical need for clean energy accelerates demands for bioenergy. The pressures on land, water, and other resources to meet these growing needs are not trivial and have both direct and indirect effects on biosphere components that range from subsurface biogeochemical cycles to atmospheric chemistry and radiation dynamics.

The potential for an Integrated Field Laboratory (IFL) to build an integrated understanding of multiscale observations and experiments in agricultural landscapes into models relevant to energy and climate is huge. An agricultural IFL would be especially relevant to understanding climate change impacts and adaptation in these systems, as well as mitigation – through both sustainable bioenergy development and the emerging potential for biomass carbon capture and storage (BECCS). Highly instrumented sites would provide understanding and an improved ability to scale physiochemical, microbial, and plant processes important to energy, water, and biogeochemical cycles. This would be achieved by a capacity to track and ultimately predict transfers across mineral, biological, and atmospheric interfaces – including ecological and climate processes that drive the cycling of water, carbon, nitrogen, and other elements, and the identification of feedbacks between the biosphere and the atmosphere. There are no locations where such a capacity now exists.

A number of important questions could be addressed at IFLs appropriately situated in agricultural systems of importance. High priority questions uniquely suited to the IFL concept and specifically focused on the need for a fundamental understanding of multiscale interactions in these widespread systems can be grouped into at least four specific topic areas:

1. Plant-microbe-fauna-soil interactions that affect plant stress tolerance and ecosystem functioning. In particular, identifying the beneficial effects of rhizosphere and endophytic communities – the plant microbiome – is a high priority prerequisite for understanding the potential for breeding improved bioenergy and other crops, and could be accomplished with advanced instrumentation and a suite of manipulative experiments and multidisciplinary analysis tools.. Potential benefits include improved plant nutrient and water use efficiencies, pest and disease resistance, tolerance to ozone and other pollutants, and soil carbon enrichment and stabilization.
2. Water movement from subsurface to atmospheric pools as mediated by plants and surface energy. In particular there is a need to couple leaf-level cellular metabolism to water fluxes, including microscale measurements of guard cell behavior and microclimates within canopies. Further, we need to couple plant-soil behavior to drivers of regional precipitation patterns – e.g. evapotranspiration as affected by natural rainfall patterns including droughts and by irrigation withdrawals – and resultant effects on convection patterns in the atmosphere, especially during the growing season.
3. The short- and long-term transformations and fluxes of carbon, nitrogen, sulfur, phosphorus, and other reactive elements as they move between subsurface, soils, and atmospheric pools. Transformations result from complex interactions of abiotic drivers such as temperature and redox conditions and biotic drivers such as plant and microbial community composition and metabolic capacities, all as mediated by the physiochemical constraints of soil and subsurface environments. All of these drivers are influenced by climate change, and agriculture has major impacts on and feedbacks to global carbon, nitrogen, and phosphorus cycles in particular.
4. Biogeochemical and plant growth models that appropriately represent microbial functions ranging

from those that provide plant nutrients to those that drive greenhouse gas fluxes or affect the long-term fate of soil carbon. There is an additional important need for a 3-d understanding of the spatial variability of organisms and processes sufficient to improve our ability to scale up knowledge from soil particles to regions and from the vadose zone to the atmosphere, and to connect this knowledge to downscaled earth system models.

All of these topics are important to our need to understand human impacts on energy and climate in general. What makes them particularly appropriate for agricultural systems are 1) the potential for newly generated knowledge to inform advanced agricultural management practices, allowing these systems to better adapt to and mitigate climate change and to produce crops, including biofuels, more sustainably; and 2) the amenability of cropping systems to experimental manipulation, making investigations of these questions in many cases more tractable and land management changes more feasible. Agricultural IFLs would thus go far towards addressing a number of crucial climate and energy questions in one of the world's most extensive ecosystem types.

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Arid Lands as a Region for an Integrated Field Laboratory

More than half of the continental United States qualifies as arid or semi-arid, spanning from the Central to Southwestern United States. These lands exist where the amount of precipitation is less than the evaporative demand. Governed by a delicate balance between precipitation and temperature, arid lands are by their very definition operating at the edge. Arid regions are also the parts of the United States undergoing the most rapid land transitions and where population growth will continue to accelerate urban expansion over the next 50 years. They are regions subject to large interannual variations (such as the mega-drought now gripping California) and are regions likely to be impacted by the anticipated climate change events of tomorrow. Increased human demand for water will further restrict water availability for wildland ecosystems. Thus, the potential roles of carbon, water, and energy cycles, key issues of an IFL, are of paramount interest in these extensive regions ranging from Kansas City to Los Angeles and from Fargo to Dallas. Speaking of arid lands alone as potential IFL locations is without context. The increasing signature of human activities together with other environmental stresses on the landscapes of arid lands are the pressing issues that warrant an IFL in this part of the United States. It is important to consider the concept of an arid IFL in the context of a gradient, tethered in an urban location at one end and extending to the natural arid/semiarid ecosystems that supply essential resources to cities at the other end.

One critical aspect that distinguishes arid lands from other parts of the United States is the essential role of transported water. Unlike coastal and river-based human settlements with better water access, water is the “oil” that must be transported to “fuel” and sustain the human enterprise in these parts of the world. Often this development involves long distance transport, such as in the Colorado River Basin and California Central Valley, feeding aridland cities such as Los Angeles and Phoenix. In other places, urban development in valleys is tightly coupled to nearby mountains, such as in Denver and Salt Lake City. The limited availability of water decouples the carbon and energy cycles from the water cycle, posing very interesting questions that can be addressed in arid lands. Of course, it is the variance, such as the long-term droughts plaguing the West today that bring these issues to the forefront.

The key issues relevant to consideration of an arid land IFL are much the same as those described in the “urban transect” document submitted to the DOE BERAC on February 19, 2015. That is, a gradient between arid/semiarid and urban systems would address key issues called for in the BERAC Charge letter, including rapid land-use changes are occurring that intensify water, carbon, and nutrient cycles and where the impacts of current and future intensification of energy, carbon, and water cycles could lead to higher uncertainties in predictions of regional and global models

The grand challenge questions for an IFL along an arid wildland-to-urban gradient include

- What are the energy, water, and GHG flows of urban systems in a changing environment?
- What are the drivers, controls, and feedbacks between the Earth System and humans systems from the global scale to finer grain scales more immediately relevant to the human experience?
- How can this knowledge inform Earth System communities?
- How can this information be used to inform stakeholders about ways to mitigate environmental impacts and lead to more resilient and sustainable urban systems?
- To which extent can biological and ecological processes be applied to build more water and energy efficient cities and settlements?

Much of the new urban expansion and population growth over the next 50 years will occur in arid and semi-arid regions of the world, away from the major waterways and coastal zones. Recognizing that factor is an important consideration in suggesting arid lands as a high priority region to consider when placing an IFL. With anticipated climate changes and increased resource demands, an IFL in the arid regions of the United States would be an exciting investment with long-term benefits to the DOE and to society.

The following individuals contributed to this white paper

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Coastal systems as a candidate for future DOE Integrated Field Campaigns

Major scientific questions and issues for coastal systems could include:

- What are the energy, water, and material flows through coastal systems, and how are they mediated by human activities and land use?
- To what extent are different types of coastal systems under significant stress from the consequences of sea-level rise, and do human influences on these systems constrain or enhance their resilience?
- What are the feedbacks from coastal systems to the broader Earth system, in terms of GHG's, energy, and biogeochemistry?
- What ecological processes lead to greater resilience of coastal systems to external stresses?
- How does the history of long-term settlement and other human activities influence the character and dynamics of current coastal systems?

More than 50% of the US population lives in coastal counties, and more than a million are added to that number each year. Coastal areas, in aggregate, are thus the most densely populated part of the US. But in addition, they consist of natural ecosystems ranging from rocky intertidal regions to sandy beaches, from salt marshes, sea grass beds, and mangroves to muddy subtidal bottoms. Each of these ecosystems provides valuable ecosystem services that are often overlooked yet hold the promise to our sustainable future. Yet increasingly, these ecosystems are altered by human activities that cause numerous deleterious consequences. For example, coastal ecosystems buffer coastlines from storms and filter nutrients but they are often severely altered by development patterns. And coastal marine systems provide essential nursery habitat and food supplies for a multitude of birds, fish, and other characteristic species, that only support economically valuable fisheries but also have deep cultural and recreational value. In addition, coastal regions are a portal for transportation and economic activity - vital not only to site-specific port cities, but to the country as a whole.

A critical ecological feature of coastal systems that could be taken advantage of in integrated field campaigns is the coupling to both inland terrestrial ecosystems and to coastal marine systems. The future development of coastal systems is thus a function of human intervention and stresses, fluxes of materials from upland watersheds, and the role of rising seas and storm intensity as major stressors from the marine interface.

Because of the extreme importance of human population density and economic activity in coastal systems, as well as their unique ecological functioning, integrated field campaigns might take advantage of two different kinds of transect-based studies, analogous to those discussed in the urban systems workshop of January 2015. One type of transect might extend from upland watershed boundaries through the coastal region itself, into coastal marine systems. As an example of such a transect, one might think of the region encompassed by the Chesapeake Bay Program, where the determinants of water quality and biological productivity of the Bay depend not only on its internal processes, but on a wide range of land-uses in the watershed, from upland forest through urban areas and agricultural land near the Bay itself.

A second potential type of transect could be oriented from more to less intensive human activity. Because coastal systems are so densely populated, it should be feasible to determine transects that essentially go from more to less perturbed by human activity and land use, while going through ecologically similar landscapes. Such transects could in principle yield information on the resilience and robustness of these coupled human-natural systems.

These two types of transects are clearly not entirely independent of each other, and should a coastal system be designated as a site for an intensive field campaign, a scientific planning effort would need to highlight the major questions and sampling design for the campaign.

Because of the rapidly changing nature of coastal systems, an integrated field campaign anchored on the coasts could provide important information for DOE to contribute to a greater understanding of the resilience of combined human and natural systems.

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Mountains as a Region or a Focal Point of Environmental Gradients for an Integrated Field Laboratory

Mountains are water towers of the world. Through orographic forcing, mountains effectively harness water vapor into fresh water in the form of precipitation, snowpack, and runoff. How mountains redistribute fresh water in time and space is an important aspect of the global water cycle. About 60 – 90% of water resources originate from mountains worldwide. Many highly populated regions rely almost entirely on water derived from the mountains, making them especially vulnerable to changes in mountain water supply. Mountain water resources support not only human activities, they are also vital to the diverse ecosystems and habitats in the mountain environment.

There are strong observational evidences that mountain water resources are being threatened by global warming trends that alter the timing and amount of water delivered by mountains. Observations and modeling suggested that warming trends are amplified in elevated regions compared to the lowlands. The upper tropospheric amplification of global warming is well understood in the tropics as the atmosphere maintains a moist adiabatic structure, but in the extratropics, snow albedo feedback is an important contribution to the elevated warming. As mountains are an integral part of the Asian and North and South American monsoons, elevated warming may have important influence on the monsoon circulation and water cycle. The diminishing mountain snowpack and changes in soil moisture can also increase wildfires and susceptibility of vegetation to insect infestation, and threaten bio-diversity as habitats migrate upward with the tree line.

By nature of the topography and river networks that connect mountains with the valleys and plains, mountains are natural focal points of environmental gradients, and their influence can extend much beyond local mountains. For example, mountains provide important forcing for large-scale atmospheric circulation and affect precipitation in remote areas through teleconnections. Individual convective cells triggered over mountains can propagate far downstream and organize into mesoscale convective systems that are responsible for nocturnal, heavy precipitation in regions such as the U.S. Great Plains. Mountain-plain circulation plays an important role in the spatial and temporal distribution of aerosols that modulate clouds and precipitation. The partitioning of water, energy, and biogeochemistry from bedrock to canopy is strongly influenced by the topographic gradients associated with mountains. Peak flows from snowmelt or precipitation driven runoff from the mountain headwaters can effectively mobilize carbon that cascades through the lowlands and plains and contribute importantly to the carbon and nutrient cycles.

Mountain water resources are vital to energy production. Through their controls on water availability and the nexus of water and energy, such as hydropower generation and water for power plant cooling, mountains influence the global water, energy, and biogeochemical cycles and the basic needs (energy, water, and food) of the human populations far downstream. Conversely, impoundments of mountain streamflow to meet water demand from urban centers and agricultural areas downstream have significant impacts on mountain hydrology. Therefore, the down-gradient and up-gradient interactions between mountains and their neighboring urban, agricultural, arid, and coastal areas must be better understood and modeled for predicting future changes.

Earth system models have limited skills in simulating atmospheric, hydrologic, cryospheric, and ecological and biological processes in mountains, because the large spatial heterogeneity is not adequately resolved, and the complex processes, their interactions, and their cascading effects are not well understood or represented in models. There are also significant gaps in measurements because of challenges in adequately sampling across large spatial heterogeneities and uncertainties in remote sensing over complex terrains (e.g., beam blockage, frequent cloudiness). River discharges are not routinely measured in many remote mountain watersheds.

Key science questions that can be addressed by a mountain IFL or an IFL with a gradient between mountains and downstream areas (e.g., urban, arid and semi-arid, and aquatic systems) include:

- How will water fluxes and storages (e.g., precipitation, snowpack, runoff) in mountains change predictably with ongoing and future warming? What are the roles of atmosphere, surface and subsurface, vegetation and biogeochemical processes in modulating the response to warming?
- How may climate change in mountains exacerbate or attenuate extreme weather events in the future?
- How will climate change in mountains influence vegetation, disturbance, and competition for new habitats? What are the impacts of these changes (e.g., albedo, root hydrology, soil carbon) on the energy, water, and biogeochemical cycles? What determines recovery after disturbances and the future regimes?
- How will changing mountain snowpack influence water supply, and what are the implications to nutrients loading, water quality, and energy production?
- What are the impacts of mountains on global circulation components (e.g., ITCZ, monsoon)? How will climate and environmental changes in mountains influence those large-scale systems and climate sensitivity and feedback on mountain processes?
- What level of heterogeneity must be captured by models to predict water, energy, and biogeochemistry flow in mountains and in environmental gradients anchored on mountains?

The objective of an IFL is to improve model predictive capability. The above science questions can be addressed with an IFL that leverages existing measurements at ARM and Ameriflux sites, NSF Critical Zone Observatory (CZO), Long-Term Ecological Research (LTER), and NEON. Measurements from bedrock to top-of-atmosphere are needed to quantify the spatial distributions of energy, water, and biogeochemical fluxes and storages. Because of the tremendous small-scale heterogeneity, surface measurements must be complemented by remote sensing data. Mobile/relocatable flux towers, radars, manned or unmanned aircraft, and surface/subsurface measurement capabilities will be needed to characterize the spatial distributions. These capabilities are also essential to improve sampling of propagating systems (e.g., organized convection) and episodic, extreme weather events (e.g., wildfires).

Field campaigns should be designed and directed to address critical gaps to improve models. Mountains represent an excellent testbed for DOE ACME, which has adopted approaches to represent subgrid topographic effects on atmospheric and terrestrial processes in watersheds. While the current implementation only accounts for subgrid orographic clouds and precipitation and subsequent impacts on surface fluxes and storages, future research can extend the subgrid framework to represent topographic effects on radiation, thus better delineating the distinct topographic influence on energy, water, and vegetation (Figure 1). With models playing a key role, an IFL can target specific model improvements such as scale-aware physics and subgrid representations, microbe-plant interactions, vegetation dynamics, and disturbance, mortality, and recovery.

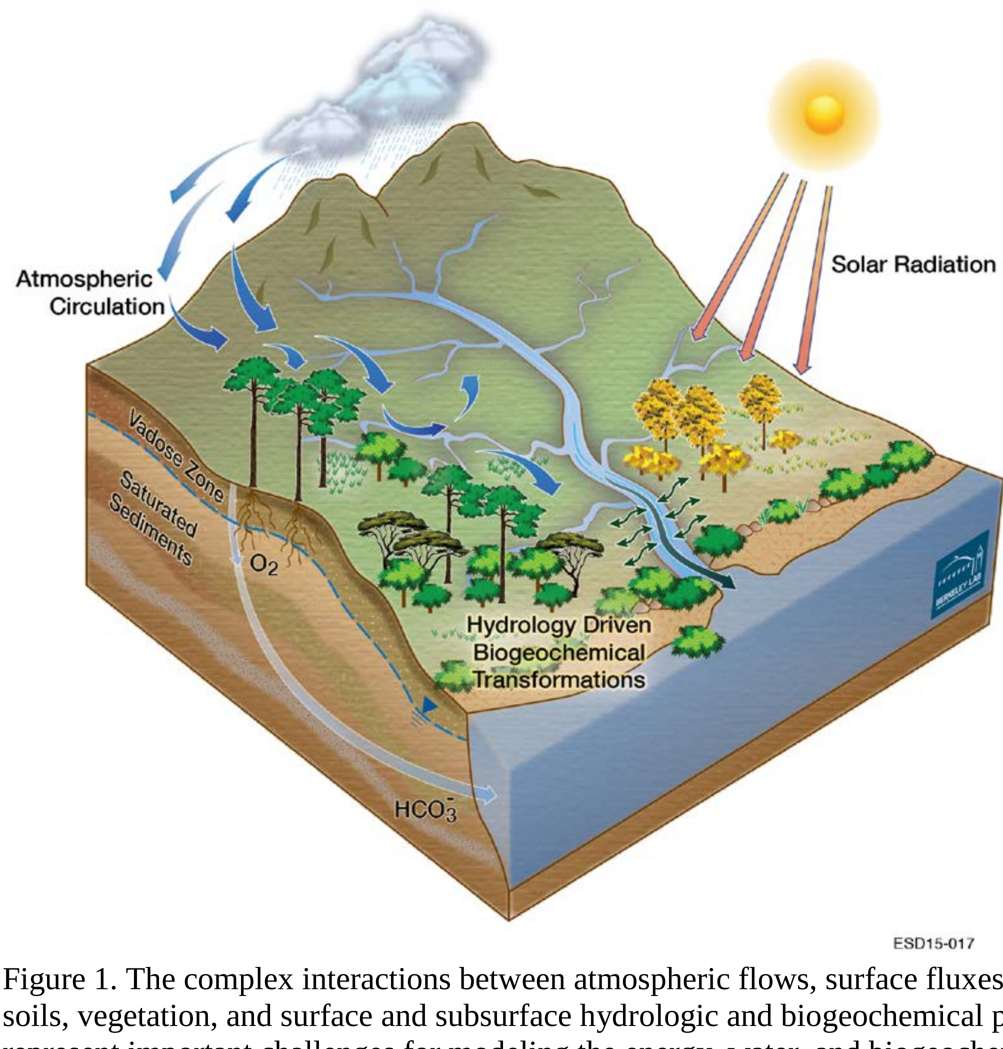

Figure 1. The complex interactions between atmospheric flows, surface fluxes, radiation, soils, vegetation, and surface and subsurface hydrologic and biogeochemical processes represent important challenges for modeling the energy, water, and biogeochemical cycles in mountains (Source: Susan Hubbard).

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A Draft Report of the

BERAC Workshop on Input for Development of an Integrated Field Laboratory With a Focus Incorporating Urban Systems as Part of Human – Earth System Interactions

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1.0 Introduction

In late September 2014, Dr. Patricia Dehmer, Acting Director, DOE Office of Science, requested that BERAC explore concepts for and provide advice on the potential development of Integrated Field Laboratories (IFLs); Acting Director Dehmer's charge letter is presented in Section 9 of this report. This charge letter asked for recommendations based on a recent report in which BERAC identified the IFL as one of three integrated and complementary components of an envisioned future BER Virtual Laboratory (BERAC 2013). This Virtual Laboratory would include IFLs for field observations and experiments, a Biosystems Frontier Network (BFN) for understanding processes across scales, and Cyberinfrastructure, Analytics, Simulation, and Knowledge Discovery (CASK) for scaling and simulation activities.

As initially described by BERAC in 2013, the IFL was envisioned as observational field capacities that "… integrated and expanded vertically (from the bedrock to the atmosphere) and geographically (across key geographic regions)." Moreover, the IFLs should be highly instrumented laboratories that build on existing BER observatory and modeling investments addressing the driving forces of change (e.g., ACME, AmeriFlux, ARM, and EMSL). Thus, it is expected that the IFLs would serve "…as validation points for deepening scientific understanding of the major drivers and consequences of environmental change arising from both natural variability and human activities." In considering development of IFLs, the BERAC (2013) report suggested that an IFL should expand on BER's Next Generation Ecosystem Experiments (NGEE) concepts, which are currently under development in arctic and tundra ecosystems.

In the initial October 2014 BERAC discussion of the charge letter, the Committee discussed a central recommendation within the BERAC 2013 report - that "… IFLs would be located in environments representative of large, rapidly changing regions or areas strategically important for the bioeconomy." The BERAC discussion quickly focused on a consideration of couple natural-human systems, including urbanizing regions, as greatly understudied ecosystems where

- Rapid land-use changes were occurring that intensified water, carbon, and nutrient cycles
- The role of changing energy sources and the nature of future urban development could lead to unpredictable future emissions scenarios and therefore increased uncertainty about the drivers of climate change
- The integrated bi-directional connectivities between natural and human-built systems and the drivers of change were not well understood and could lead to future surprises not currently predictable based on existing models
- The impacts of current and future intensification of energy, carbon, and water cycles could lead to higher uncertainties in predictions of regional and global models

While the BER research has historically focused on the carbon, water, and energy cycles of natural ecosystems and how these processes impact our climate system, we lack an equivalent understanding of couple natural-human systems, such as urban and urbanizing systems. Thus, the BERAC requested that two of its members (Jim Ehleringer and Tony Janetos) plan a workshop that would inform the BERAC at its February 2015 meeting of the potential for an IFL that embraced urban, human-built ecosystems as a central coupled natural-human system focus and that also included consideration of how such IFLs might integrate with existing BER infrastructure and capacities. The workshop took place January 29-30, 2015.

Urban areas represent the dominant anthropogenic source of CO_2 emissions. The combination of large, concentrated carbon fluxes in urban regions in the US and worldwide makes cities large and dynamic elements of the global carbon cycle (Hutyra et al. 2014). In 2013, global fossil fuel and cement production emissions were estimated as 9.9 PgC yr^{-1} (Boden et al. 2013, Andres et al. 2014), with over 70% of fossil fuel CO_2 emissions attributable to urban areas (Energy Information Administration 2013). Annual urban CO_2 emissions are nearly triple the net terrestrial or oceanic carbon sinks.

Cities have the potential to serve as "first responders" for climate action to reduce emissions (Rosenzweig et al. 2010, 2011). Many of our future urban areas do not yet exist. As such, we have the potential to shape future urbanization patterns to reduce emissions. However, our current estimates of urban-scale carbon fluxes are highly uncertain; the few attempts at assessing urban-scale uncertainty suggest 50–100% error in the emissions estimates (NRC 2010, Rayner et al. 2010). Errors of this magnitude make it nearly impossible to assess progress towards emissions reductions goals or the efficacy of urban mitigation policies.

Relevant to IFL discussions and to coupled natural-human systems, climate policy is emerging at the local and urban scales due, in part, to limited international and national policy progress (Rosenzweig et al. 2010, 2011). As one example, California Assembly Bill 32 (AB32) requires greenhouse gas emissions reductions to 1990 levels by 2020. Further, over 1000 mayors have signed the U.S. Mayors Climate Protection Agreement, which commits them to meeting or exceeding the Kyoto Protocol reductions within their cities. Major global initiatives in the financial sector target cities for obvious reasons, particularly focused on risk, creating new, large scale demand for scientific data and analytics, e.g., the RISE Initiative hosted at the UN International Strategy for Disaster Risk Reduction to better encode disaster risk in finance. The Global Risk Model will launch in March, 2015, creating the opportunity for the first time to juxtapose global financial models with Earth system models with a shared interest in extreme events, GHG emissions, critical infrastructure, vulnerabilities and resilience at the nexus of energy, water, food and climate. Cities are critical participants in the implementation of climate policy because the urban landscape is where the majority of industry operates, consumers live, and power is consumed. It is at the municipal-to-regional scales that knowledge about local mitigation options, costs, and opportunities is the greatest.

1.1 A Workshop Exploring an IFL Incorporating Coupled Natural-Human-Built Ecosystems

The January 2015 IFL workshop was designed to explore issues necessary to respond to Acting Director Dehmer's request for specific recommendations related to development of an IFL. Her requests were interpreted as providing recommendations that would

- Expand on the concept and provide recommendations on development of the IFL
- Identify major cross-cutting gaps in BER science that require development of IFLs
- Consider IFL as traversing representative ecosystems and building off existing BER investments
- Focus on understanding processes that drive energy, carbon, water, and biogeochemical cycles
- Address hypotheses relevant to impacts of and adaptation to climate change and sustainable bioenergy development
- Define criteria for selecting IFL sites and identify examples of possible IFL locations
- Provide opportunities for collaboration with other federal agencies

In designing the IFL workshop, Acting Director Dehmer's request was translated into a series of questions that would provide the fundamental information necessary to respond to the charge letter. Specifically, these broad questions were developed and fed into the design of a workshop that focused primarily on discussions with but a single presentation to set the stage:

- What are the key science and/or technological questions driving the need for an IFL?
- How do those science/technological questions best encompass needs from BER as a whole?
- Is there a need for an IFL that encompasses natural and human-built systems (i.e., urban)? If so, who is seeking this information and/or would be a user of this information? Is the urban-to-natural gradient poorly understood with respect to earth system predictability? If not, identify alternative key IFL ideas not previously discussed at the last BERAC meeting.
- What should be the essential criteria for selecting one or more IFL sites?
- What cross-cutting gaps in BER sciences limit our understanding of the predictability of earth science and how will this IFL address these gaps in knowledge?

1.2 Tapping the Expertise of University and National Laboratory Scientists

In addition to BERAC members, the workshop was designed to bring in five distinct scientific groups whose perspectives would complement each other:

- Faculty from research universities
- Managers and directors from national laboratories
- Research scientists from BER facilities
- Program managers from other federal agencies
- Scientists leading NSF-funded projects that had a strong urban focus

The participants able to accept our invitation represented different areas and are listed in Section 6 of this report.

1.3 Background to prepare for the workshop

To prepare for this workshop, participants were provided with extensive background materials. The specific documents are listed in Section 7.0, but included

- The charge letter
- Recent BERAC and BER reports relevant to the virtual laboratory concept, designing the next generation of ecosystem experiments, and BER strategic plans
- A recent publication summarizing a multi-agency sponsored workshop on the urban carbon cycle
- A series of 10 solicited and strategic white papers from the academic and national laboratory communities on topics specific to modeling, IFL-related planning requirements, BER capacities and gaps, and conceptual frameworks
- Several overarching presentations on urban carbon cycle science presented at the January 26-28 North American Carbon Cycle Project meeting in Washington, D.C.

1.4 Structure of the Workshop

The workshop largely focused on input and discussion around the central key topics relevant to the development of and IFL mentioned earlier. We met either as an entire group (plenary) or divided into two groups for more intense discussions lead by a BERAC member (Jim Ehleringer and Ruby Leung) and recorded by a rapporteur (Nancy Grimm and Lucy Hutyra). The topics, in order of consideration, included

1. On future ACME modeling needs for an IFL (Peter Thornton, ORNL)
    - What are the regional and global carbon cycle modeling needs by 2020 that require data and observations from an IFL?
    - What are the spatial observation needs and resolutions to feed models in the next decade?
2. Science questions requiring an IFL
    - What are the key science questions that can be asked with an IFL, with particular attention to urban settings?
    - What could be the vision of an IFL?
3. Envisioning an IFL
    - What is the vision for what an integrated field site(s) might look like?
    - Should sites be dispersed or along gradients?
    - Relationship to previous BERAC report on Virtual Laboratory
4. What are the emerging perspectives of federal agencies on urban science?
5. Practical decisions about what goes into designing and operating an IFL
    - Challenges in the design of an IFL
    - Balance of modeling and field/laboratory research
    - Balance of empirical/experimental/modeling research
    - Implications for data management/archiving/sharing
    - How best to take advantage of national laboratory/university strengths
6. Development of conceptual models of integrated field/laboratory research approach
7. Exploring relationships between urban-based IFL concepts and activities underway in other agencies and DOE activities
8. On implementing IFLs
    - What leadership and governance considerations are critical?
    - What are the key criteria that would go into selecting an IFL?
    - What are some possible examples of urban regions appropriate for IFLs based on criteria and on existing efforts?

2.0 Exploring the Need for an IFL

The driving force for creating an IFL must be based on critical science questions of sufficient size and scale that a geographically distributed network is required to answer the science questions and to inform the wide spectrum of policy makers and stakeholders. Climate is changing and is already impacting natural and human-dominated systems across the United States (Melillo et al. 2014). Previous ecological and Earth system science research within the DOE has focused on understanding climate change impacts on natural ecosystems at smaller scales (e.g., FACE and NGEE) or a widely distributed set of observational tower sites in natural ecosystems (e.g., AmeriFlux). As a result, our understanding of the magnitude and dynamics of carbon source sinks and strengths for these natural systems in response to climate change are better understood today because of the extensive carbon cycle research funded by the DOE Office of Science as well as the other federal agencies funding carbon cycle observational, experimental, and modeling research (Michalak et al. 2011, Climate and Environmental Sciences Division 2012, Le Quéré et al. 2014).

However, we do not have an equivalent understanding of coupled natural-human systems or human-dominated systems across landscape scales, which cover an increasing portion of the terrestrial surface and are an important intensification nexus for energy use, carbon cycles, and water cycles. It is these landscapes that will increase in importance with respect to their impacts on the Earth's climate system and it is here where an IFL approach could provide critical data for an improved understanding of human - Earth system interactions. Currently, over one-half of the worlds population reside in urban areas and this proportion is projected to rise to two-thirds by the middle of the 21st century (United Nations 2011). And while urban areas currently represent a small percentage of the terrestrial surface, they are the primary user of energy and generate more than 70% of the global greenhouse emissions (Fragkias et al. 2013, IPCC 2014). The uncertainties in how the carbon, water, and energy fluxes of urban systems, natural systems, and their connectivities operate now and into the future form the rationale for developing an IFL.

If we are going to create sustainable cities and sustainable coupled natural-human systems, then we need to understand these processes to the same degree attempted in natural systems via programs, such as NGEE-Arctic and NGEE-Tropics. It is feasible to suggest that IFLs focusing on urban systems and coupled natural-human systems could also be leadership opportunities for the DOE, where partnerships would emerge with other federal agencies, the private sector, and municipalities, making sure that our science investments also had a significant and immediate return for society.

2.1 Key science questions driving the need for an IFL

At the broadest scale, the rapid growth in our understanding of the primacy of human–Earth system interactions in driving environmental changes motivates an IFL that includes the home of over half—and soon, more than two thirds—of the planet's human population. Two types of science question drive the need for an IFL. The first type includes fundamental questions about the structure and function of coupled natural-human systems, including theory and observations that lead to a basic knowledge of how these systems work—i.e., mechanistic questions. What are the component parts of the system, how do they function and interact, what are the relevant scales of interaction and the relative importance of biophysical, societal, contextual, cross-scale, and other drivers? What are the linkages between the human dominated components of systems and the environment that provisions and sustains them? How, in fact, do we define urban? The second type of question focuses on dynamics and trajectories: How are things changing? Given a decision made today, what are the possible future trajectories of urban functions? How can decision-making alter or bend the flows of carbon, energy, and water? How do altered trajectories feedback on decision-making? Are there emergent properties and what determines these properties? What might probable futures look like? Taking both of these types of questions in concert, contribute to improving our understanding of the sustainability and resilience of coupled human-natural systems.. Answering these questions aligns well with DOE's mission to ensure America's security and prosperity by addressing its energy and environmental challenges and with BER's mission to advance world-class biological and environmental research in support of DOE's mission.

From the standpoint of BERAC and its focal areas, the two question types can be combined into grand challenge questions that revolve around the concentrated use of energy in urban areas, associated alterations in energy, water, materials, food, and other resources, and consequent influences on climate and energy systems of the future. Grand Challenge Questions: **What are the energy, water, and GHG flows of urban systems in a changing environment? What are the drivers, controls, and feedbacks between the Earth System and humans systems from the global scale to finer grain scales more immediately relevant to the human experience? How can this knowledge inform Earth System communities? How can this information be used to inform stakeholders about ways to mitigate environmental impacts and lead to more resilient and sustainable urban systems?**

A multi-scaled, hierarchically nested set of science questions underlies these grand challenge questions. Science questions should: embrace the tremendous variability in intrinsic and contextual characteristics of cities; acknowledge the importance of connectivity among cities and other systems in a regional context; recognize that surprises, non-linearity, and unpredictability are likely; and allow for the possibility of game-changing futures in terms of technology, human demography, extreme events, water and food security, and shifting political climates. The following are examples of science questions related to the grand challenge questions that might drive research at an IFL:

(A) Mechanistic and core questions

- What are the energy-related GHG emissions at urban scales? What are the uncertainties on those emissions estimates?
- What processes in a large urban center control energy and mass (e.g., water) exchanges between the built environment and the atmosphere and how do we measure these fluxes?
- How do climate change, urban-suburban-exurban land use and land-use change, and GHG fluxes interact and feedback in urbanizing landscapes?
- How does the connectivity of urban, suburban, exurban, and non-urban systems in a region drive energy, carbon, water use trajectories, and how are these systems dependent upon one another and even far-distant systems?
- How do we identify and evaluate cross-scale biophysical and policy interactions that are important to urban energy, carbon, and water flows and trajectories?
- How does activity and growth in the built environment impact local and regional climate and air quality? What are the feedbacks between climate and air quality at the urban scale? How will extreme events (climate and air quality) be manifest within urban areas? How do these relationships affect the global atmosphere and are affected by it?
- Are there emergent and identifiable typologies of couple natural-human systems (typologies) that are scalable and where insights are transferable to other geographic regions? How do these typologies evolve in different parts of the globe and what is the role of the physical, geographic, or socio-economic setting in determining them?
- How do business actions/decisions influence the local and regional environment?

(B) Future-thinking questions

- What possible trajectories of urban and surrounding landscapes would enable simultaneous reductions in the rates of emissions of greenhouse gases, more sustainable use of energy, water, and other materials, and increase resilience to extreme climate events?
- Is there a reducible set of variables that control the energy trajectory for cities and urban regions? To what degree does "lock in" of technologies determine future emissions and resilience trajectories?
- What scientific and technological innovations will improve our ability to sample, estimate, and portray trajectories of key system characteristics, e.g., energy demand, GHG emissions?
- How do we envision futures for the carbon and water cycles in the face of game-changing factors, including demographics (population density, cultural histories), technology, extreme events, and general unpredictability and uncertainty of urban-related phenomena?

2.2 Modeling, Data Integration, and Collaboration as Essential Elements

While an IFL is conceived primarily as the observational component of a Virtual Laboratory, modeling will be an essential element to ensure the IFL meets its objectives. Models encapsulate our knowledge of individual components and their interactions. For urban systems, the interaction aspects are most formidable as they represent the intersection of human and natural systems, and carbon, energy, and water cycles that span a significant range of scales. Models provide a framework for integrating observations to generate comprehensive databases for knowledge discovery. They are essential tools for hypothesis testing and prediction. In urban environments with immense spatial heterogeneity, models can also play a critical role in interpreting the observations, developing measurement strategies, and testing proposed interventions to curb GHG emissions or limiting urban heat effect. To serve these functions, models must represent processes at all relevant scales to allow feedbacks that govern emergent behaviors and low probability – high-risk events that challenge sustainability. The current two-dimensional and binary representation of urban systems in Earth System Models must be transformed to capture key processes in three dimensions and as a continuum in space and time. This requires a new class of models that are extensive in their integration of multiple components and intensive in their representations of individual components at their native scales. While modeling supports the IFL in achieving its science goals, the IFL must also be designed to support the data needs for modeling. Symbiotic model – data integration is thus essential to address the key science questions of the urban systems.

Underpinning the emphasis on predictive modeling is recognition that the IFL concept must include a focus on new computational technology and software frameworks, integration of data collection, transfer, storage, analysis, and visualization, and connections to new generations of the nation's science and technology workforce. The IFL should play an important role as an incubator for new instrumentation and measurement technology. Novel instrumentation, sensors and sensor networks will be particularly critical in the highly heterogeneous urban landscape.

Data are an important language of exchange between modeling, field, and laboratory research communities. Engagement of IFL domain expertise in the modeling enterprise will have a significant focus on what is measurable, what is and how well are parameters measured, determining what is missing, and how measurements are analyzed, encoded, and shared. Some common data formats and exchange mechanisms already exist within various domains, but there is not yet an agreed-upon standard (or standards) that reach across many empirical and modeling domains. An additional challenge will be the need for incorporation of social science data with more traditional biogeochemical data as social factors will be important drivers for ecosystem processes.

3.0 Envisioning IFLs

The IFL will develop a new class of modeling tools, data management, and observational capacities to address key science questions on carbon, water, and energy cycles within human-dominated landscapes and enable transformation of future energy systems. As development of an IFL is considered, it should be viewed as an activity which is scalable and that can be replicated geographically. Consideration of coupling and the challenge that come with coupled, integrated activities must be at the forefront in the design and eventual management of an IFL consisting multiple field observational capacities spanning different ecological systems and governance institutions.

The interactions among urban systems, drivers and the flows of carbon, water, and energy within the context of an IFL are pictured in Figure 1. Key urban systems include the urban atmosphere, built systems (i.e., urban infrastructure including buildings, roads, sewers etc.), terrestrial ecosystems (soil, vegetation, animals, microbes), and aquatic ecosystems (rivers, lakes, coastal regions). Examples of key processes giving rise to flows among these systems include (a) built systems – energy production, energy consumption, water and waste treatment, (b) terrestrial and aquatic ecosystems – production and respiration, decomposition, (c) atmosphere – chemical composition, transport and circulation, heat island, and radiative forcing. The outer boxes acknowledge the direct and indirect relationships between the local scale carbon-water-energy budgets of a given city and surrounding region and, ultimately, the globe through trans-boundary fluxes as well as interconnected drivers (socio-economic, geographical, and built systems). The inner boxes contain the interfaces to the urban scale and are rife with significantly unknown processes and mechanisms that define urban behaviors that are currently not well understood and will be a focal point for successful modeling of these systems. A recognition of the importance of socio-economic drivers in explaining system evolution and flows and engagement with the social scientists will be important for answering both types of research questions envisioned for the IFL.

3.1 A Network of IFLs Recognizing Urban Development and Climate Change as Drivers

An IFL built around scientific questions that investigate the consequences of both rapid urbanization and a changing physical climate system would require several components and be best designed as an overall network. Point sampling, i.e. focusing on one or two urban centers, would not capture the heterogeneity that we already know is present in cities, whether it is population size or density, the extent of transportation networks of different types, whether cities are coastal or inland, and so forth. Nor could a small number of cities capture the heterogeneity in the relationship of the cities to their surrounding landscapes, or to those landscapes that provision the cities, whether they are nearby or distant.

Workshop participants concluded that IFL's with a strong urban component might best be thought of as a network of sampling sites that both address important questions for modeling, including both projections and exploration of scenarios, and that address important empirical questions. These questions might, for example, require the measurement of a variety of fluxes and deposition of substances from urban sources on a wide variety of spatial and temporal scales, from local to regional, and from hourly to seasonal and annual. Indeed the mechanisms of the spatio-temporal interfaces embodied in going from exurban regions to heavily populated urban areas may be a rich area of investigation and critical to effective modeling.

While there are now a growing number of scientific programs with urban components (e.g. NEON, LTER, NOAA, NIST), there appears to be limited cross-site integration. Network concepts are in their infancy and a DOE led and integrated IFL would represent a significant advancement in coupling human activities and earth system science. The IFL should be designed in such a way that there are expanded opportunities for sharing data and observations. There is a potential tension between enabling using different platforms (modeling, data, etc.) across a variety of cities and stashing core data standards and curation that will enable interoperability. A network of IFL's incorporating cities and landscapes with different characteristics would be innovative and was considered as a productive way to proceed.

3.2 What could an IFL consist of?

An urban science-focused IFL should have a complement of observations, models and integrated analyses, and enabled by an end-to-end data and information management system and high-end computational capabilities. The interdisciplinary nature of IFL science questions requires multi-layered (i.e. phenomena, time, space, etc.) data sets. This multidimensional aspect of data sets poses a major challenge and opportunity for DOE to work closely with other sister agencies (e.g. NASA, NOAA, EPA, NSF, etc.). A combination large-scale data sets and integrated human-Earth system models require access to DOE sponsored high-end computational capabilities.

At its core, an IFL would consist of thoroughly instrumented sites in both urban and surrounding landscapes (suburban, exurban, rural). Measurements would range from air sampling for emissions and/or deposition information, to meteorological and flux measurements, to activity measurements, such as intensity and timing of traffic and energy use. For urban sites, a comprehensive inventory of buildings, use, and building energy use is also a key component. Strategically coupled measurements of water use, runoff, and other elements of the hydrologic cycle could also advance DOE's long-standing interest in the nexus of energy-water-land resources. Access and strong relationships to local urban decision and policy-makers who can also facilitate access to necessary local data is also important for DOE's investments to have both scientific and practical outcomes.

An IFL would also have the development and evaluation of models as an intrinsic feature. This concept has driven the planning of existing DOE field programs (e.g., NGEE-Arctic), and it should do so here as well. These could be process-based models, regional models that couple human and natural dimensions, and integrated assessment models. An assessment of existing modeling work can help identify key uncertainties areas on which to focus observational efforts. A hierarchical suite of models and measurements should be used to assess questions at varying scales. Data management must also be a central feature of an IFL, both because of the anticipated richness and variety of measurements and modeling results, but also because DOE urban-centric IFL's will also exist in a virtual network of urban research sponsored by other federal agencies.

3.3 Existing BER Facilities and Programs as Essential Elements of an IFL

We expect the National Laboratories to play important roles in the development of IFLs with an urban focus. They have the continuity and the infrastructure necessary to instrument, maintain, and manage the data from IFLs for the time that such field campaigns should be maintained, which we feel is at least a decade. The National Labs have played similarly crucial roles in the development and maintenance of other DOE field programs, or large experimental programs, such as NGEE-Arctic, the Biofuels Research Centers, ARM, and EMSL. However, the specific sites or transects chosen must be competed on the basis of the degree to which they are suitable for addressing important scientific questions.

The primary questions initially addressed would be oriented toward basic understanding and process-oriented questions, e.g., What are the magnitudes and processes involved in human-natural system feedbacks at the urban scale (heat islands, energy, soil carbon, etc.). Additional questions may involve mitigation-related questions, e.g., What configuration of cities and technologies could alter the curve of greenhouse gas emissions downwards? Or they could involve adaptation-related questions, e.g., are some configurations of urban and exurban/rural landscapes more resilient to a changing physical climate system and extreme events than others? Or, more likely, they could involve both types of questions. But when considering how to understand the joint roles of urban systems and a changing physical climate system, IFLs should be planned and selected on the basis of how well they address the underlying science questions. Many cities and surrounding landscapes may meet these criteria, and both the national laboratories and the university community should develop strong relationships and take advantage of existing measurement programs that IFLs can be built on.

3.4 Challenges in the Design of an IFL

There are multiple challenges inherent in proposing a field laboratory in urban areas: phasing of implementation, data types and interoperability, siting of instrumentation, scale of measurement, identification of parameter measurements that don't exist or perform at the levels needed, involvement of stakeholders, integration with existing federal observation systems, quality control, and education and outreach. Governing and coordinating the research at urban IFLs will be considered separately.

We advocate a model for implementing an IFL that occurs in phases and, where possible, utilizes existing capabilities and investments. Major field observation systems or experiments often are conceived without considering the conceptual frameworks, interoperability, and modeling from the start, yet these elements are essential for a next-generation observatory. The gaps in understanding revealed by modeling systems from the outset will ensure efficiency in design of IFL components and variables to be measured. It also is critical that a data handling structure be in place, preferably one that can communicate with other observatories and with non-science data. For example, the National Information Exchange Model (NIEM) used to share information by non-science projects such as emergency operations centers and the Open Geospatial Consortium (OGC) for science both attempt to bring together spatial data across the federal agencies. The diversity of information to be gathered demands early consideration of how that data can be made widely available (interoperability). Further, the importance of a modular, extensible design from the inception of an IFL lies in its capacity to assimilate and integrate research on important drivers and responses that are perhaps beyond the purview of the DOE (e.g., public health and well-being). Thus, a phased implementation strategy will enable the continual integration and dialogue among models, diverse data, observations, local and regional issues that frame the issues, and associated research.

Siting an urban IFL in and around cities will present unique challenges. Instrumenting the IFL will have to recognize privacy concerns. Capturing the spatial heterogeneity will most likely require engaging multiple types of land owners. While it may be tempting to set up instrumentation in parks to simplify siting, such components would be inadequate to capture the heterogeneity of the system.

Indeed, tremendous spatial heterogeneity at multiple scales is a hallmark of urban regions and the heterogeneity in biophysical features is mirrored by heterogeneity in built structure and social structure (Figure 2). Past studies have mostly avoided urban areas where the mix of anthropogenic and natural fluxes is complex and difficult to observationally isolate. Urban areas are a heterogeneous matrix of stationary objects like pipes, buildings and trees, and constantly moving people and cars that all exchange carbon, each with their own cycles. Urban biological fluxes are poorly quantified, but have the greatest uptake when anthropogenic emissions are highest – effectively, aliasing some portion of the emissions. These urban-scale sources and sinks are integrated with background inflows of air to result in poorly constrained variations in the local atmospheric mixing ratios. While our emerging space-based monitoring capacities can measure CO_2 through the entire atmospheric column (XCO2), column measurements cannot partitioning concentration observations into the biological sinks or fossil fuel emissions occurring within the landscape.

Furthermore, the scales of measurement should refer back to a hierarchy of science questions and framing models, recognizing the potential for cross-scale interactions and emergence at regional scales of phenomena driven by local interactions. Development of novel measurement strategies and techniques to capture the complexity and dynamics of the urban environment should be part of the deliverables for an initial phase.

Given a focus on local-to-regional drivers and feedbacks in climate, energy, water, and land use, early involvement of local and regional stakeholders will be essential to success of an IFL. Just as an iterative process of models informing the design of data collection and data informing model improvement should be integral, developing and refining science questions in light of the particular knowledge needs of stakeholders will ensure relevance. Stakeholders include local and regional policymakers, managers, and planners; members of the business community, and various publics, in addition to academic and federal researchers and modelers. The IFL can draw from the rich experience of the two NSF urban LTERS in figuring out how to engage and take advantage of the experiences and perspectives of their stakeholders. An especially important connection to make early on in the process of establishing an IFL is with existing federal observing systems and large-scale field experiments (see Section 4.2).

Finally, workshop participants recognized that open data access, interoperability, and integration of sensor-derived data with models in real time, such as might be envisioned for this facility, is currently in the "culture" of only a small segment of the scientific community. Therefore, there is a real need to integrate an educational and social component in the IFL, to train the next generation of modelers and analysts of massive quantities of highly heterogeneous information.

3.5 Governance and Coordination

The "hardware" of an IFL as envisioned by workshop participants is a network of several place-based, regional-to-local-scale measurement systems along urban–rural gradients in contrasting settings. But the IFL clearly will be more than this, as a platform for model–data integration, data sharing and access, and communication and interaction with other observational activities. The governance of such a network thus will entail the goals of IFL oversight, ensuring interoperability, and coordination with other DOE resources and other federal agencies. A consortium model for governance of the IFL seems most appropriate to achieving these goals. Membership in this consortium would include agencies, academic organizations, and stakeholders; the consortium might be governed by a board that includes the lead scientists of each IFL site, a technical group that oversees interoperability and data quality control, and interagency group. Workshop participants suggested that the US Global Change Research Program or some other consortium-type organization under the Office of Science and Technology Policy could be charged with coordination, while DOE retains the position of a top-level manager/principal.

In planning for the IFL to be a network from the start, it will be critical to select proven leaders, think through the rationales for siting of individual regional-gradient-local instrumentation installations, and assemble the team for creating the data/modeling infrastructure. Competing the individual IFL sites through a formal solicitation process would allow the best ideas to emerge but might make integration more challenging; an alternative would be to run a pre-proposal competition, and once finalists are selected, impose some coordination on the incipient network.

4.0 DOE Leadership is Critical in Developing an IFL Integrating Urban, Managed, and Natural Systems

Few federal agencies have an organizational structure and history of long-term commitment to the infrastructure and research necessary to address ecological field projects. In many ways, the DOE is uniquely positioned with AmeriFlux, ARM, EMSL, FACE, and NGEE representing examples of long term commitments that lead to advances in our understanding of the earth system and its components. If the DOE decides to move forward with development of an IFL network, the agency is well positioned to provide leadership for development of IFLs and to coordinate with other agencies.

4.1 DOE has Unique Capacities to Lead Development of an IFL Infrastructure

Energy-relevant research that advances the cycle of observing, understanding, modeling and testing are distinguishing features and unique assets of the DOE. Core capabilities include Earth system modeling and integrated modeling of the human-natural system; pioneering work in high-resolution climate modeling methodologies to produce robust regional climate projections, including information on extremes, feedbacks, variability and change, and thresholds and tipping points; comprehensive and innovative portfolio of research through the ARM Climate Research Facility long-term and field campaign observations; EMSL offers expertise and leading-edge research instrumentation, supercomputing capabilities, and open-source software to investigate and simulate key molecular- and atomic-level biological, chemical, and physical interactions that give rise to larger scale phenomenon. EMSL supports users from academia, national laboratories, other federal agencies, and industry; and data infrastructure provides internationally recognized data sets and tools to support community research.

CDIAC provides quality-assured data on the carbon cycle and terrestrial ecosystems. Climate model output and selected ARM and CDIAC observational data are provided to the community through the Earth System Grid Federation. DOE also supports a broad range of data, analysis, and modeling capabilities related to residential and commercial buildings, the appliances and equipment within those buildings, and site-specific renewable energy technologies and resources.

4.2 DOE Big Idea Summit

There is also an IFL-like urban initiative being developed through the FY 15 DOE Big Idea Summit (BIS) that is being run by the DOE Office of the Undersecretary, March 2-3. 2015. An initiative called the "Urban System Science and Engineering" (USSE) was selected in early February 2015 as a finalist topic to be presented at the BIS in April 2015. The USSE is described as a systems approach to understanding global urban impact and enhancing urban sustainability, resiliency, and operational efficiency. It was put together rather quickly by a group of DOE labs, including ANL (lead), LBNL, NREL, PNNL, and ORNL. It has significant similarities with the IFL, but is much more focused on the energy infrastructure aspects of urban systems than scientific understanding. While different, it does demonstrate DOE's increasing broad interests in coupled natural-human systems and their interactions.

4.3 An Emerging Federal Interest in Urban Systems by Other Federal Agencies

Urban ecosystems have been receiving growing attention from many federal agencies as a location for major land cover and land use change impacts, a dominant and growing source of greenhouse gas emissions, and as a unique ecological and biogeochemical system. Key federal agencies currently supporting related research in the urban sphere include NSF, NOAA, NASA, and NIST. However, none of the programs approaches an integration, scale, and connectivity as envisioned for an IFL. In Fall 2013 the USGCRP and the Carbon Cycle Interagency Working Group sponsored an urban carbon cycle workshop to explore current capabilities, emerging needs, and key science questions. The workshop resulted in a series of papers broaching the topic from natural science, social science, engineering, and interdisciplinary perspectives (Chester et al. 2014, Hutyra et al. 2014, Marcotullio et al. 2014, Romero-Lankao and et al. 2014). The President's Council of Advisors on Science and Technology (PCAST) held a workshop on *Technology and the Future of Cities* on 12 February 2015 to examine how cities' use of energy, water, transportation, and other services could be utilized more effectively into the future. Thus, there is a broad range of interest in this topic from the operational levels of agency to the leadership in the White House, and will demand the types of information and tools discussed during the IFL workshop.

Within the NSF, there are three distinct and non-overlapping field-based efforts:

- The NSF has continuously supported two urban Long-Term Ecological Research (LTER) sites in Baltimore and Phoenix since 1997 to understand urban social-ecological systems.
- From 2009 through 2013, the NSF and the US Forest Service supported ~22 pilot studies to explore establishing additional Urban Long-Term Research Areas across the US (e.g., Boston, Chicago, Cincinnati, Los Angeles, Miami, New York, and Phoenix), but that program is no longer operational.
- Within the NSF National Ecological Observing Network (NEON) currently under development, five urban sites have been identified. The NEON urban sites will be located near Boston, MA, Bozeman, MT, Salt Lake City, UT, Ponce, PR, and Tucson, AZ. Each of these sites is considered

"relocatable" and based on community input could be moved to different (urban) locations after a 5-8 year deployment beginning in 2017.

The NEON sites will include tower-based instrumented facilities and long-term biological observations, but it will be up to the scientific community to determine the specific science questions to be asked within and/or among urban facilities. Extensive measurements are planned at the urban NEON sites, including eddy flux, trace gas measurements, hyperspectral imaging, lidar mapping, and soil microbial analysis among an extensive suite of ecological observations.

The NOAA Atmospheric Chemistry, Carbon Cycle, and Climate (AC4) Program has a current focus that includes the urban carbon cycle and air quality with current projects in Boston, Indianapolis, Salt Lake City, and Los Angeles. In addition, NOAA Air Resource Laboratory (ARL) conducts research on regional air quality, the Global Monitoring Division (GMD) measures key atmospheric constituents that provide a powerful baseline for carbon dioxide emissions, and the Chemical Sciences Division conducts field programs focused on air quality and the urban environment. NOAA's National Weather Service and National Environmental Data and Information Services also produce a host of environmental data and information dissemination directed at the urban environment. NOAA's Regional Integrated Sciences & Assessments (RISA) program supports research teams that help expand and build the nation's capacity to prepare for and adapt to climate variability and change. Many of the eleven RISA involve interactions with cities.

NASA's science programs utilize satellite-based and aircraft-based observing platforms to advance knowledge of Earth as a system to meet the challenges of environmental change. Specific related NASA programs include Terrestrial Ecology, Applied Sciences, Interdisciplinary Science, and the Land Cover/Land Use Change. While NASA does have specific urban programs, several NASA assets provide urban-scale observations on urban atmospheres and air quality (OCO-2, OMI, SCIAMACHY, etc.), urban extent and intensity (e.g., Landsat, NPP, DMSP, VIIRS), and potentially even urban vegetation (upcoming GEDI mission). The upcoming TEMPO (hourly measurements, North American focus; 2019 launch) and TROPOMI (daily coverage at 7x7 km; 2016 launch) satellites will offer air quality (CO, O_3, CH_4, SO_2, etc.) measurement at spatial and temporal scales that have never existed before but would couple with urban-scale IFL observations. Integration of surface observations and models with this next generation of satellite data can provide a powerful ground validation for the space-based observations and a scaling tool to dramatically extend the impact of the IFL activities.

NIST has supported major urban efforts in the Indianapolis, Los Angeles, and Northeast corridor regions. These are focused on GHG emissions measurements and modeling activities and would benefit from improved understanding of uptake processes. NIST also recently launched a Greenhouse Gas and Climate Science Measurements program to improve measurements and standards to support emissions reporting, verification, and satellite calibrations.

There are clear opportunities for coupling common urban science research activities that could lead to stronger interactions and greater integration among federally funded urban research at these federal agencies. In particular, it was suggested that the DOE could take a leadership position through development of an IFL network and coupling this urban IFL network with existing observatories and research at other federal agencies.

5.0 Criteria for Identifying Specific Urban Systems as Part of an IFL Network

Workshop participants agreed that a successful IFL network and development of individual IFLs required a strong central design and coordination as discussed earlier. At the same time, it was agreed that no single IFL could sufficiently characterize all urban systems or natural-to-urban gradients. Thus, to be most effective in addressing the science questions, a network of four to five geographical distributed IFLs undergoing different ranges of urbanization and expansion would be required. So, the question becomes what criteria do we recommend that the DOE consider in identifying specific geographic regions or landscapes that will constitute an IFL network? Figure 3 is an effort to organize four categories of potential IFL locations that will assist the DOE in selecting specific cities and landscape to form the IFLs.

5.1 Climate, Ecological, and Social Axes

The design of an IFL must both recognize the importance of contrasting climate-ecological axes as well as social-institutional axes. Additionally any acceptable design of IFLs must build on both existing BER facilities and from the foundation already developed in key areas across the US today. Figure 3 represents one approach to assess the strengths and weaknesses of different urban-natural regions that could be selected as IFL(s). Central to the consideration is a recognition of four different thematic considerations: (a) climate and ecological factors, (b) social and institutional factors, (c) the extent to which this region builds upon or complements both existing (BER) relevant research infrastructure and existing infrastructure from other federal agencies, and (d) the extent to which foundational data and studies exist to build upon in development of an IFL. Within each of these four sectors, there are a number of different criteria to consider. Each topic sector might include 4-6 criteria factors to consider and to contrast with alternative IFLs locations. The individual factors could be scaled from 0-100 and then linked to create a spiked web as shown in Figure 3. One effective approach for comparing among IFL candidates would be to compare the 'spider webs' to assess the extent of opportunity associated with different IFL options.

If the IFL is considered as a network of regions in contrast to a single region, then the contrasting differences in climate, ecological landscape, and drivers of land-use change become important factors to consider in building an integrated network of IFLs. Climate factors such as temperature and precipitation could naturally lead to considerations of how land-use changes and urbanization are driven by factors such as water availability and by factors such as energy need. Ideally, consideration should be given to construction of an IFL network consisting of 4-5 urban-natural gradients across the US. Water availability and the sensitivity of natural ecosystems to changes in water and the cascading influences of water availability on urbanization could be one gradient to consider. In terms of land-use and climatic gradients, one could imagine gradients such as from (a) bioenergy-agricultural systems to urban centers, (b) forests to urban centers, or (c) interior-to-coastal gradients.

5.2 Municipal Interest and Established/Ongoing Research Activities to Build Upon

Municipal engagement from the design to implementation phases of the IFL will be crucial for success. Given that urban areas include a unique set of opportunities and challenges, municipal and regional government engagement from the outset is requisite to partnership formations and will facilitate access to data, sampling locations, policy documents, and stakeholders. In fact, cities in many locations are already moving forward with efforts that would facilitate development of an IFL integrating climate changes with urban and regional perspectives on carbon, water, and energy cycles. The positive response of public officials and their motivation and ability to act may, in fact, be a key to the eventual success of the urban IFL concept. Municipalities will be both producers and consumers of data and insight from the IFL. All of the urban locations discussed below have some level of municipal engagement, but strong local commitments to the scientific products and process from the local municipalities, private industry, and academia will result in a lower barrier to entry and higher probabilities of scientific success.

5.3 Examples of Urban Locations Where an Established Research Foundation Exists

Research foundations for an IFL exist in nearly every US urban center. Key US sites with extensive research activity focused on the carbon cycle, energy systems, and climate/energy balances include the following (in alphabetical order; not an exhaustive list):

- Baltimore, Maryland – e.g., Pickett and et al. (2011)
- Boston, Massachusetts – e.g., McKain et al. (2015)
- Chicago, Illinois – e.g., Wuebbles et al. (2010)
- Denver, Colorado – Cohen and Ramaswami (2014)
- Indianapolis, Indiana – Turnbull and et al. (2015), Gurney et al. (2012)
- Knoxville, Tennessee
- Los Angeles, California – Kort et al. (2012)
- New York, New York - Rosenberg et al. (2010), Rosenzweig et al. (2010)
- Phoenix, Arizona – Grimm et al. (2013)
- Portland, Oregon – http://www.pdx.edu/esur-igert/publications
- Salt Lake City, Utah – Strong et al. (2011), McKain et al. (2012)
- San Francisco/Oakland, California – Peischl and et al. (2012)
- Seattle, Washington –http://cses.washington.edu/cig/res/ia/waccia.shtml, Rosenberg et al. (2010)

The observational, modeling, and social networks present across these cities vary in their intensity and focus, but all include components that could advance the IFL objectives. The suite of emissions work, atmospheric observations, and inverse atmospheric modeling efforts currently underway in Boston, Los Angeles, Indianapolis, and Salt Lake City are of particular relevance for these IFLs grand challenges. The experiment design for the IFL should consider both common drivers of modern urban centers, while paying attention to their unique settings and attributes. In this context, the workshop participants discussed briefly the idea of potential gradients across such network of urban centers/systems, and the potential use of remote sensing and aerial facilities (e.g. ARM, NASA and NCAR) for their integrated analyses.

6.0 Participants in the IFL Workshop

The invited participants able to accept our invitation represented different areas including:

BERAC members
- Jim Ehleringer, University of Utah
- Anthony Janetos, Boston University
- Ruby Leung, Pacific Northwest National Laboratory

Faculty from research universities
- Kevin Gurney, Arizona State University
- Lucy Hutyra, Boston University
- Molly Jahn, University of Wisconsin
- John Lin, University of Utah
- Steven Wofsy, Harvard University

National laboratories
- Ghassem Asrar, Pacific Northwest National Laboratory
- William Collins, Lawrence Berkeley National Laboratory
- Jack Fellows, Oak Ridge National Laboratory
- Robin Graham, Argonne National Laboratory
- Martin Schoonen, Brookhaven National Laboratory

BER facilities
- Alex Guenther, ARM
- Nancy Hess, EMSL
- Giri Palanisamy, ARM Data Archive
- Steve Smith, ARM
- Peter Thornton, ACME
- Stan Wullschleger, NGEE

Other federal agencies
- Kenneth Jucks, NASA
- Elisabeth Larson, NASA
- Kenneth Mooney, NOAA
- Diane Pataki, NSF
- James Whetstone, NIST

NSF-funded projects with urban and natural ecosystem foci
- Nancy Grimm, Arizona State University, Long Term Ecological Research (LTER) site
- Henry Loescher, National Ecological Observatory Network (NEON)

7.0 Background Materials Provided to Workshop Participants

To prepare for this workshop, participants were provided key BERAC and BER reports, including

- BERAC. 2013. BER Virtual Laboratory: Innovative Framework for Biological and Environmental Grand Challenges; A Report from the Biological and Environmental Research Advisory Committee, DOE/SC-0156. science.energy.gov/ber/berac/reports/. Washington, D.C.
- Climate and Environmental Sciences Division. 2012. Strategic Plan, Biological and Environmental Research, DOE Office of Science. U.S. Department of Energy, Washington, D.C.
- Hanson, P. J. and Workshop Participants. 2008. Ecosystem experiments: understanding climate change impacts on ecosystems and feedbacks to the physical climate. Report of the workshop on exploring science needs for the next generation of climate change and CO_2 experiments in terrestrial ecosystems, 14-18 April, 2008, Arlington, Virginia.

Participants were also provided a recent multi-authored journal publication on urban carbon cycles that was the result of a 2013 multi-agency workshop in Boulder, Colorado:

- Hutyra, L. R., R. Duren, K. R. Gurney, N. Grimm, E. A. Kort, E. Larson, and G. Shrestha. 2014. Urbanization and the carbon cycle: Current capabilities and research outlook from the natural sciences perspective. Earth's Future 2:473-495.

In addition, we solicited brief white papers on topics thought to be critical to the discussion, including

- A white paper on Next-Generation Ecosystem Experiments focusing on using process studies to guide, parameterize, and evaluate hierarchical scaling framework for NGEE Arctic. Submitted by the NGEE Arctic Team.
- A white paper for developing a hierarchical scaling framework to model arctic landscapes in a changing environment. Submitted by Peter Thornton and the NGEE Arctic Science Team.
- A white paper posing several critical science questions related to fossil fuel emissions and to biospheric fluxes. Submitted by Lucy Hutyra.
- A multi-authored 2014 publication in Earth's Future describing urbanization and the carbon cycle, with specific reference to current capabilities and research outlook.
- A summary report from ANL describing a 2013 workshop on urban landscapes and climate change. Submitted by Beth Drewniak and ANL colleagues.
- A white paper on urban data, including a conceptual framework, challenges in collecting social-economic data, considerations in data collection, and integrating natural and social science data. Submitted by Robin Graham.
- A white paper on integratin and scaling in urban systems, with lessons from landscape ecology. Submitted by Stan Wullschleger and Budhendra Bhaduri.
- A white paper on the ACME data and modeling needs that would require implementation of the Integrated Field Laboratory. Submitted by Peter Thornton.
- A white paper to identify gaps and offer recommendations to improve understanding of human-dominated systems and managed landscapes. Submitted by from Margaret Torn and the AmeriFlux community.
- A white paper based on April 2014 workshop focused on interaction between urban environment and atmosphere at City College of New York (CCNY), co-organized by BNL and CCNY.

8.0 Workshop Agenda and Details

Workshop 1 to Address Charge Letter to BERAC on Defining an Integrated Field Laboratory
Germantown, MD, January 29-30, 2015

Workshop objective:

- To conduct an initial 2-day workshop to address the September 23, 2014 Charge Letter from Acting Director Patricia Dehmer on recommendations for an Integrated Field Laboratory (IFL).
- This workshop will build off the BERAC discussion during the October 2014 BERAC meeting that focused on urban possibilities for inclusion into an IFL.
- The results of this workshop would be provided to BERAC members for discussion at the February 2015 meeting.
- The result of this initial workshop and of discussions at the February BERAC meeting would provide the basis for decisions on a future workshop and/or the next steps in providing a report to Acting Director Dehmer by September 2015.

BERAC organizers:

James Ehleringer, University of Utah, jim.ehleringer@utah.edu (cell 801-971-6004)
Anthony Janetos, Boston University, ajanetos@bu.edu
Ruby Leung, PNNL, Ruby.Leung@pnnl.gov

Workshop time: January 29-30, 2015 (2-day period)
Workshop location: DOE, Germantown, MD (Room A-410 and additional breakout rooms)

Rapporteurs:

- Lucy Hutyra, Boston University
- Nancy Grimm, Arizona State University

DOE contact: Mike Kuperberg, Michael.kuperberg@science.doe.gov, 301-903-3511

Key issues to address in different sessions of the initial workshop and essential to report back to BERAC

- What are the key science and/or technological questions driving the need for an IFL?
- How do those science/technological questions best encompass needs from BER as a whole?
- Is there a need for an IFL that encompasses natural and human-built systems (i.e., urban)? If so, who is seeking this information and/or would be a user of this information? Is the urban-to-natural gradient poorly understood with respect to earth system predictability? If not, identify alternative key IFL ideas not previously discussed at the last BERAC meeting.
- What should be the essential criteria for selecting one or more IFL sites?
- What cross-cutting gaps in BER sciences limit our understanding of the predictability of earth science and how will this IFL address these gaps in knowledge?

Thursday, January 29th

8:00 Leave hotel

9:00-9:45 Initial presentations and discussions (plenary)

- Welcome – DOE official and BERAC members
- Background on charge to BERAC; what is being sought from BERAC (Mike Kuperberg)
- Summary of previous BERAC discussion about the charge that have moved beyond the initial charge letter (Tony Janetos)
- Timeline and anticipated products from this initial workshop (Jim Ehleringer)

9:45-10:15 On ACME carbon cycle modeling needs for an IFL (Peter Thornton, ORNL)

- What are the regional and global carbon cycle modeling needs by 2020 that require data and observations from an IFL?
- What are the spatial observation needs and resolutions to feed models in the next decade?

10:15-10:30 Break

10:30-12:00 Science questions requiring an IFL (Two break out groups; each with lead and rapporteur)

- What are the key science questions that can be asked with an IFL, with particular attention to urban settings?
- What could be the vision of an IFL?

12:00-12:15 Break

12:15-1:00 Working lunch with summary reports and discussion from the rapporteurs of the breakouts

1:00-2:00 Envisioning an IFL (Plenary discussion led by Tony Janetos, Jim Ehleringer, and Ruby Leung)

- What is the vision for what an integrated field site(s) might look like?
- Should sites be dispersed or along gradients?
- Relationship to previous BERAC report on Virtual Laboratory

2:00-2:15 Break

2:15-3:30 What are the emerging perspectives of federal agencies on urban science (Plenary panel discussion led by Tony Janetos, Jim Ehleringer, and Ruby Leung)

- Diane Pataki – NSF
- James Whetstone – NIST
- Nancy Grimm - LTER
- Ken Jucks – NASA
- Libby Larson - NASA
- Hank Loescher - NEON
- Ken Mooney – NOAA

3:30-5:00 Practical decisions about what goes into designing and operating an IFL (Two break out groups; each with lead and rapporteur)

- Challenges in the design of an IFL
- Balance of modeling and field/laboratory research
- Balance of empirical/experimental/modeling research
- Implications for data management/archiving/sharing
- How best to take advantage of national laboratory/university strengths

5:00 Adjourn for the day

Friday, January 30th

8:00-9:00 Summary of day 1 activities (Plenary panel discussion led by Tony Janetos, Jim Ehleringer, and Ruby Leung)

- Science questions
- Emerging federal perspectives
- Designing and implementing an IFL

9:00-10:00 Development of conceptual models of integrated field/laboratory research approach (Two break out groups; each with lead and rapporteur)

10:00-10:15 Break

10:15-11:00 Summary reports and discussion on conceptual models from the rapporteur of two groups

11:00-12:00 Exploring relationships between urban-based IFL concepts and activities underway in other agencies and DOE activities (Plenary discussion led by Tony Janetos, Jim Ehleringer, and Ruby Leung)

- Possible coordination with Biofuels Research Centers
- Possible coordination with plans for field campaigns (e. g. TES, AmeriFlux, ARM sites, NGEE-Arctic)
- Relationship to NEON and LTERs
- Relationship to NSF, NOAA, and NIST urban research efforts
- Relationship to ACME modeling
- Relationship to other DOE BER research interests

12:00-1:30 Working lunch revisiting the key science questions requiring an IFL and how new and existing DOE facilities could fit into this larger, more integrated picture

1:30 Writing assignments (to be presented at February 26-27, 2015 BERAC meeting); initial report authored by BERAC members (Ehleringer, Janetos, Leung) and rapporteurs

2:00 Adjourn

9.0 Charge Letter

Department of Energy
Office of Science
Washington, DC 20585

September 23, 2014

Dr. Gary Stacey
Associate Director, National Soybean Biotechnology Center
Department of Microbiology and Molecular Immunology
271E Christopher S. Bond Life Sciences Center
University of Missouri
Columbia, MO 65211

Dear Dr. Stacey:

In 2013, BERAC prepared a report on Virtual Laboratories, i.e., "BER Virtual Laboratory: Innovative Framework for Biological and Environmental Grand Challenges." The Virtual Laboratories report stated that the innovation most needed for the BER community is a framework that allows seamless integration of multiscale observations, experiments, theory, and process understanding into predictive models for knowledge discovery.

A key component of the Virtual Laboratory was identified as the Integrated Field Laboratory (IFL). Integrated and expanded vertically from the bedrock to the atmosphere and geographically across key geographic regions, IFLs would exploit existing BER field observatory investments, such as sites associated with the Atmospheric Radiation Measurement Climate Research Facility, AmeriFlux Network, subsurface biogeochemical field study sites, and the Next-Generation Ecosystem Experiments. These highly instrumented IFLs would traverse representative ecosystems and focus on understanding and scaling fundamental dynamical, physical, biogeochemical, microbial, and plant processes that drive planetary energy, water, and biogeochemical cycles. Ideally, IFLs would also provide the necessary data to address hypotheses at multiple scales of observation relevant to the impacts of and adaptation to climate change, and sustainable bioenergy development.

As we move towards a BER priority to enhance our multi-disciplinary approach for the environmental (including climate) sciences and exploit BER assets, we are challenged to describe the multidisciplinary characteristics of environmental observatories that in turn can rapidly advance BER science. I am now charging BERAC to recommend the major next initiatives for field-based research that capture a multi-disciplinary approach and build on observations and modeling. As part of this charge, BERAC should (1) define the criteria for selecting sites for future BER field-based research and (2) prioritize the sites identified or described. The following should be considered when making your recommendations:

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- Identify candidate geographic regions that are poorly understood with respect to earth system predictability, e.g., under-studied, under-sampled, climatically sensitive, and/or a source of significant prediction uncertainty;
- Identify major cross-cutting gaps in BER sciences, that limit our understanding of the predictability of the earth science across numerous geographic regions;
- Exploit unique BER assets, e.g., ARM, JGI, EMSL, and other major field activities, where possible;
- Exploit science capabilities of both CESD and BSSD, where relevant;
- Provide opportunities for collaborations involving other federal agencies; and/or
- Exploit emerging scientific discoveries and advanced technologies from other disciplines, e.g., computational, observational, sensing, visualization.

In preparing its response to this charge, BERAC should consider other materials prepared by BERAC, such as the report noted above, materials prepared by the Program, and workshop reports. In 2012, the Climate and Environmental Sciences Division released its strategic plan (http://science.energy.gov/~/media/ber/pdf/CESD-StratPlan-2012.pdf), with a goal to advance predictability of the earth system. The plan included a set of goals and scientific questions that, in turn, can form the basis of future environmental observatories able to exploit a combination of field observations and sophisticated modeling. The 2008 workshop report, Ecosystem Experiments, "Understanding Climate Change Impacts on Ecosystems and Feedbacks to the Physical Climate" (http://science.energy.gov/~/media/ber/pdf/Ecosystem_experiments.pdf), that led to the Next Generation Ecosystem Experiments, may also be a useful resource.

I would like to receive a progress report on this charge at the next meeting in early 2015 and a final report at the summer or fall meeting in 2015. I look forward to what should be a stimulating and useful report. Many thanks for your contributions to this important effort.

Sincerely,

Patricia M. Dehmer
Acting Director, Office of Science

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Figures associated with BERAC IFL draft report

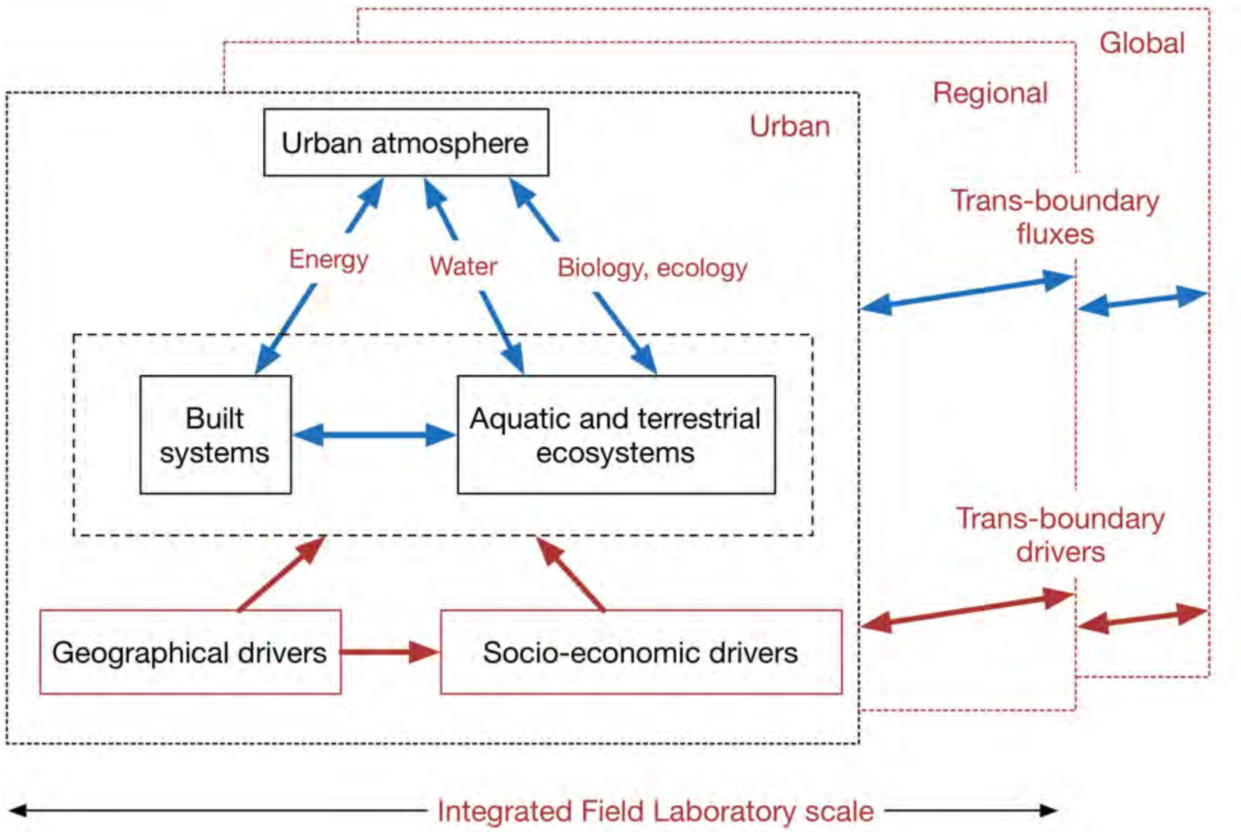

Figure 1. Interactions among carbon, water, and energy cycles in urban system within the context of an Integrated Field Laboratory (urban to regional scales). In this schematic, we show key urban reservoirs and processes (black boxes), carbon-water-energy fluxes (blue arrows), major drivers (red boxes), and examples of process linkages (red arrows). Key urban reservoirs include the atmosphere, built systems, land and terrestrial ecosystems, and aquatic systems (including waters and aquatic ecosystems). The outer boxes acknowledge the direct and indirect relationships between the local scale carbon-water-energy budgets of a given city and surrounding region and, ultimately, globe through trans-boundary fluxes as well as interconnected drivers (socio-economic, geographical, and built systems). Based on a figure that originally appeared in Hutyra et al. (2014).

Figure 2. Spatial heterogeneity at multiple scales is a hallmark of urban regions and the heterogeneity in biophysical features is mirrored by heterogeneity in built structure and social structure. Images courtesy of Peter Thornton.

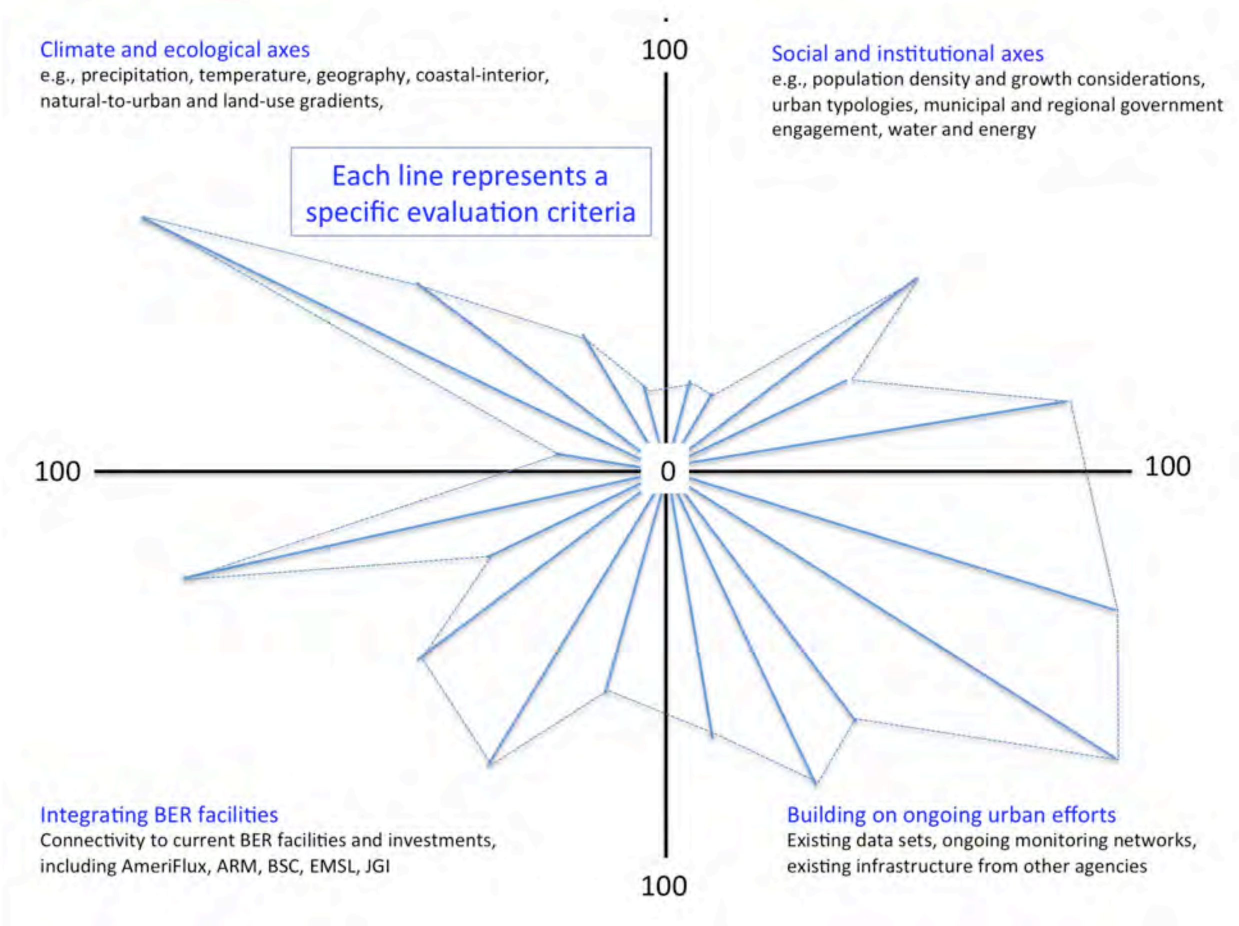

Figure 3. A 'spider web' conceptual presentation of four key topic areas and their topic components central to decisions on how to identify, compare, and select potential Integrated Field Laboratory sites. The four thematic areas are (a) climate and ecological axes, (b) social and institutional axes, (c) integration of BER facilities, and (d) building on existing urban science efforts. The lines represent the strength of activity or relevance of a relative measure, ranging from 0-100. As any consideration of potential IFL sites is likely to have both strengths and weaknesses, the spider diagram allows the designer to visually picture and compare across potential IFL sites.