

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<sub>2</sub> 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<sup>-1</sup> (Boden et al. 2013, Andres et al. 2014), with over 70% of fossil fuel CO<sub>2</sub> emissions attributable to urban areas (Energy Information Administration 2013). Annual urban CO<sub>2</sub> 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 an IFL mentioned earlier. We met either as an entire group (plenary) or divided into two groups for more intense discussions led 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 world's population reside in urban areas and this proportion is projected to rise to two-thirds by the middle of the 21<sup>st</sup> 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<sub>2</sub> through the entire atmospheric column (XCO<sub>2</sub>), 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 NGEF 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<sub>3</sub>, CH<sub>4</sub>, SO<sub>2</sub>, 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 Wullschlegel, 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/](http://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<sub>2</sub> 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 integration 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](mailto:jim.ehleringer@utah.edu) (cell 801-971-6004)

Anthony Janetos, Boston University, [ajanetos@bu.edu](mailto:ajanetos@bu.edu)

Ruby Leung, PNNL, [Ruby.Leung@pnnl.gov](mailto: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](mailto: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 29<sup>th</sup>**

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 30<sup>th</sup>**

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 Biological and Environmental Research  
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](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

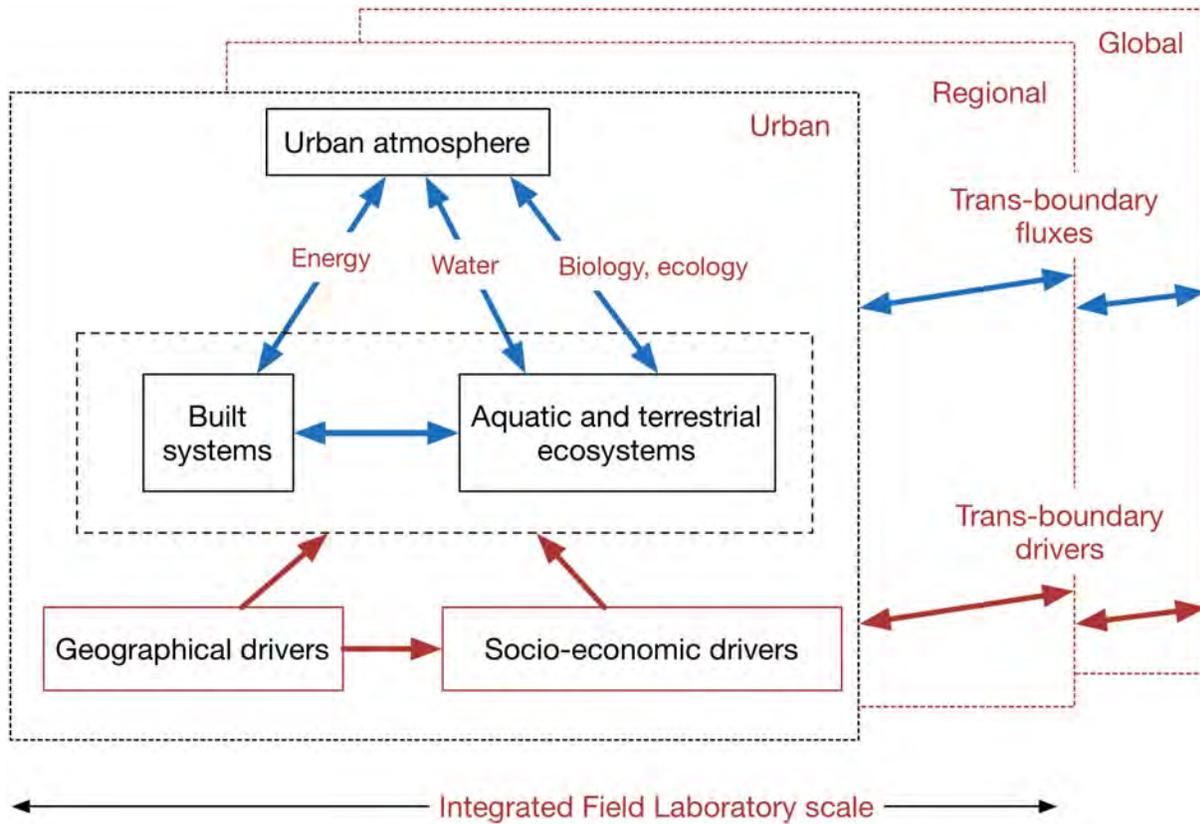


Figure 1. Interactions among carbon, water, and energy cycles in urban system within the context of an Integrated Field Laboratory (urban to regional scales). In this schematic, we show key urban reservoirs and processes (black boxes), carbon-water-energy fluxes (blue arrows), major drivers (red boxes), 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.

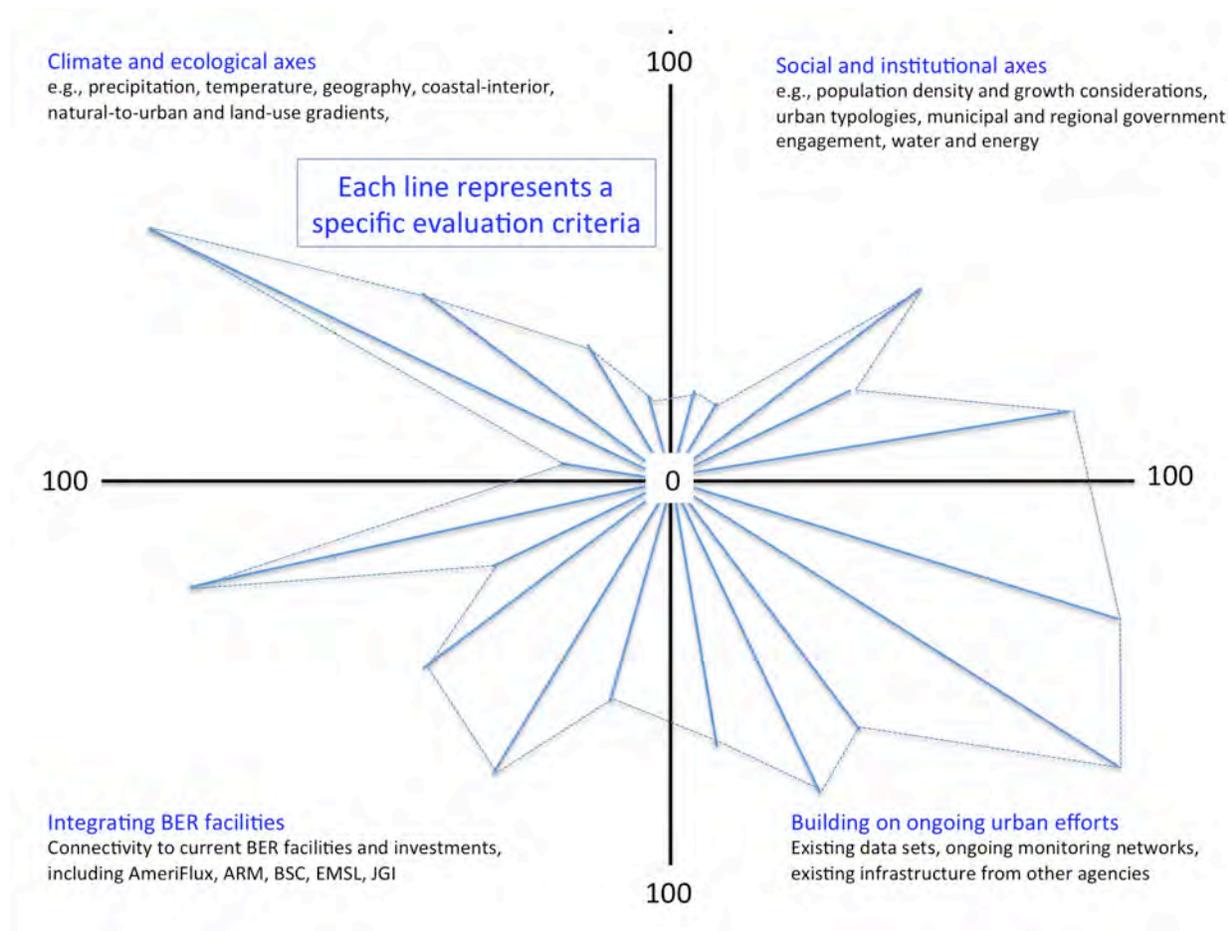


Figure 3. A 'spider web' conceptual presentation of four key topic areas and their topic components central to decisions on how to identify, compare, and select potential Integrated Field Laboratory sites. The four thematic areas are (a) climate and ecological axes, (b) social and institutional axes, (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.