EMSL Ecotron Workshop Report

June 2020

C Jansson

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Pacific Northwest National Laboratory
Richland, Washington 99354

Summary

The Environmental Molecular Sciences Laboratory (EMSL) Ecotron Workshop was held at Pacific Northwest National Laboratory (PNNL) on May 20–21, 2019. Twenty five guests represented the EMSL User Executive Committee (UEC); the Ecotron facilities in Montpellier, France and at the University of Hasselt, Germany; the plant-atmosphere SAPHIR-PLUS facility in Jülich, Germany; the EcoCELL platform at the Desert Research Institute (DRI) in Reno, NV; Biosphere 2 and the University of Arizona, Tucson, AZ; and the EcoPOD platform at Lawrence Berkeley National Laboratory (LBNL), Berkeley, CA. Staff at PNNL also attended.

The attendees met one and a half days to discuss the possibilities of an EMSL Ecotron, scientifically and administratively linked to EMSL as a user capability. Of specific interest was 1) feedback from the UEC for the perceived interactions between an EMSL Ecotron and the EMSL user community and 2) information about the setup and operation of the European Ecotron macrocosm platforms and the somewhat related capabilities at DRI, Biosphere 2, and LBNL.

In general, the attendees thought an EMSL Ecotron would be a valuable capability, with the potential to place EMSL and PNNL in the forefront of environmental sciences. It was readily realized that, by integrating with existing EMSL capabilities, an EMSL Ecotron would be an extraordinary resource for the EMSL user community. However, the UEC members had a significant concern that an EMSL Ecotron would serve a small number of users, tie up staff and instruments for other users, and require a different paradigm for user proposals with multi-investigator projects over several years. The UEC also cautioned that the high costs for the Ecotron ($9M in construction and $1.9M in annual operation) would remove resources from the users, unless EMSL's general budget increased.

The presentations about the European Ecotrons and ensuing discussions about their macrocosm platforms were enlightening, informing the attendees of the challenges with managing the complex systems and continuous financial support. The representatives from DRI and Biosphere 2 echoed these sentiments.

Ultimately, the attendees reached the consensus that incorporating an Ecotron into the EMSL capability suite as presented was likely not feasible given the demand for high and sustained funding, disruption of the EMSL user program with multi-investigators and long-term projects, and challenging management structure. More research was suggested to evaluate the prospects and options for an EMSL Ecotron, including developing a cost-benefit analysis and sustainability plan to maximize the use and occupancy of an EMSL Ecotron, as well as partnering with existing macrocosm facilities in the U.S., such as DRI. Furthermore, the attendees advised socializing the EMSL Ecotron vision more with the Biological and project managers and directors in the U.S. Department of Energy (DOE) Office of Science, Office of Biological and Environmental Research.

Acronyms and Abbreviations

AnaEE	Analysis and Experimentation on Ecosystems
BER	Biological and Environmental Research
BVOC	Biogenic volatile organic compounds
DOE	U.S. Department of Energy
DRI	Desert Research Institute
EMSL	Environmental Molecular Sciences Laboratory
LBNL	Lawrence Berkeley National Laboratory
PNNL	Pacific Northwest National Laboratory
UEC	User Executive Committee
VOC	volatile organic compounds

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1.0 Introduction

Just as the term *Phytotron* is used to designate enclosed compartments devoted to growing and studying plants, the term *Ecotron* refers to enclosed compartments for the studies of ecosystems. Ecotrons come in different sizes, formats, and degrees of sophistication. The most relevant systems for an Environmental Molecular Sciences Laboratory (EMSL) Ecotron are the outdoor macrocosm platforms like the Montpellier Ecotron in France and the Hasselt Ecotron in Belgium. Other examples include the EcoCELLS, which are indoor macrocosms at the Desert Research Institute (DRI) in Reno, NV, the EcoPODS, which are indoor mesocosms at Lawrence Berkeley National Laboratory (LBNL) based on the German iDiv EcoUnit chambers, and the Biosphere 2 in Oracle, AZ and operated by University of Arizona, Tucson, AZ. Also of relevance for the EMSL Ecotron vision is the SAPHIR-PLUS in Jülich, Germany, an atmosphere-simulation chamber linked to an environmentally controlled dynamic (flow-through) plant chamber for investigations of biogenic volatile organic compounds (BVOCs).

The concept of an EMSL Ecotron was conceived as part of the exit strategy for the iPASS (integrated Plant-Atmosphere-Soil Systems) Pacific Northwest National Laboratory (PNNL) Initiative that was initiated in spring 2015 and approved March-May, 2016. The general idea of a large-scale ecosystem science capability linked to EMSL was first tested by a benchmarking trip. Christer Jansson, David Koppenaal, and Alex Guenter from EMSL, and Vanessa Bailey from PNNL toured the Ecotron facility in Montpellier, France, the SAPHIR-PLUS, and other facilities in Jülich and Munich, Germany, in August 2015. The EMSL Ecotron vision was presented to Paul Bayer and other Biological and Environmental Research (BER) project managers in Washington D.C. in January 2017. They gave a positive response and recommended a closer connection with the Montpellier Ecotron as a means of evaluating the EMSL Ecotron idea. Such a connection has since been established.

In concert with the agreement for plant-biology research under PREMIS, and with aerosol research regaining attention in the EMSL user program, the EMSL Ecotron concept was put back on the table. The 2019 EMSL Strategic Plan states: *EMSL is developing conceptual plans for an Ecosystem Simulator (EcoSim) Facility that will enable investigation of several cubic yards of intact native ecosystem under tightly controlled and heavily instrumented above and below-ground conditions.* A more detailed presentation of the EMSL Ecotron vision was given during a Skype meeting with BER in February 2019 and also by Kirsten Hofmockel as the acting EMSL Chief Science Officer during the 2019 Genomic Sciences Program (GSP) meeting later in February. To further develop the concept and obtain information and feedback from the scientific community, a workshop was held at PNNL May 20-21, 2019.

2.0 Workshop attendees

Workshop attendees were selected to reflect the feasibility, value, and configuration of an EMSL Ecotron, the needs and reactions from the EMSL user community, and the potential for partnerships with existing facilities.

Invited guests:

- Richard Ferrieri, Professor, University of Missouri, Columbia, MO (EMSL User Executive Committee [UEC] Chair)
- Stephen Decker, Group Research Manager, National Renewable Energy Laboratory, Golden, CO (UEC member)
- Anne Johansen, Professor, Central Washington University, Ellensburg, WA (UEC member)
- Melanie Mayes, Senior Staff Scientist, Oak Ridge National Laboratory, Oak Ridge, TN (UEC member)
- Alexandru Milcu, Director of the Montpellier Ecotron Facility, Montpellier, France
- Natalie Beenaerts, Director of the University of Hasselt Ecotron Facility, Hasselt, Belgium
- Jenny Mortimer, Researcher (EcoPOD group), LBNL, Berkeley, CA
- Laura Meredith, Director of Rainforest Research, Biosphere 2, Assistant Professor, University of Arizona, Tucson, AZ
- Scot Hulbert, Professor, Associate Dean, Washington State University, Pullman, WA
- Sarah Garre, University of Liege, Belgium
- Jay Arnone, Professor, DRI, Reno, NV
- Alexander Laskin, Professor, Purdue University, West Lafayette, IN
- Romy Chakraborty, Staff Scientist, Ecology Department Head, LBNL (via Skype)
- Astrid Kiendler-Scharr, Director of the SAPHIR-PLUS Facility, Jülich, Germany (via Skype)

Staff at PNNL:

- Amir Ahkami, Staff Scientist
- Vanessa Bailey, Staff Scientist
- Harvey Bolton, Deputy for Management and Operations
- Dave Cowley, Senior Research Scientist
- Charlette Geffen, Chief Sciences and Tech Officer
- Pubudu Handakumbura, Staff Scientist
- Nancy Hess, Staff Scientist
- Kim Hixson, Senior Research Scientist
- Kirsten Hofmockel, Staff Scientist, Acting Chief Science Officer
- Swarup China, Chemist
- Christer Jansson, PNNL Laboratory Fellow
- David Koppenaal, PNNL Laboratory Fellow
- Douglas Mans, EMSL Director
- Lee Ann McCue, Staff Scientist
- Mary McGown, Administrative Assistant
- Jim Moran, Staff Scientist
- Theva Thevuthasan, Staff Scientist
- Lili Pasa-Tolic, PNNL Laboratory Fellow
- Albert Rivas-Ubach, Project Scientist
- Tim Scheibe, PNNL Laboratory Fellow
- John Shilling, Chemist

Several staff at PNNL attended the day and a half workshop as their time allowed.

A group photo of the workshop attendees is shown in Figure 1.

Figure 1. EMSL Ecotron Workshop attendees on the EMSL lawn, May 20, 2019. (Photo by Andrea Starr)

3.0 Presentations

3.1 Presentation: Existing EMSL capabilities: *Kirsten Hofmockel*

Kirsten Hofmockel gave an overview of EMSL's integrated capability platforms in the context of the user program and EMSL's strategic science.

3.2 Presentation: EMSL Ecotron proposal and vision: *Christer Jansson*

Christer Jansson described the proposed EMSL Ecotron capability with concepts borrowed from the European Ecotron facilities in Montpellier, France and University of Hasselt, Belgium but with added features for image-based phenotyping and integrated atmospheric reaction and cloud chambers. He referred to the subsequent presentations by Alex Milcu and Natalie Beenaerts for details regarding the Montpellier and Hasselt Ecotrons. Jansson pointed out the importance of being able to receive natural sunlight at close to 100 percent intensity and spectrum and, similar to the Montpellier and Hasselt macrocosms, as an alternative to receiving natural sunlight, the dome could be covered and computer-controlled light-emitting diode arrays could light the facility to precisely simulate the light quality and intensity changes that occur in the field throughout a solar day. The EMSL Ecotron units would reproducibly simulate dynamic changes of environmental conditions (or playback recorded field conditions) occurring in the outdoor environment. The continuous image-based phenotyping would be accomplished via camera panels with hyperspectral, LiDAR (Light Detection and Ranging), chlorophyll fluorescence, red-green-blue, near-infrared and/or thermal cameras.

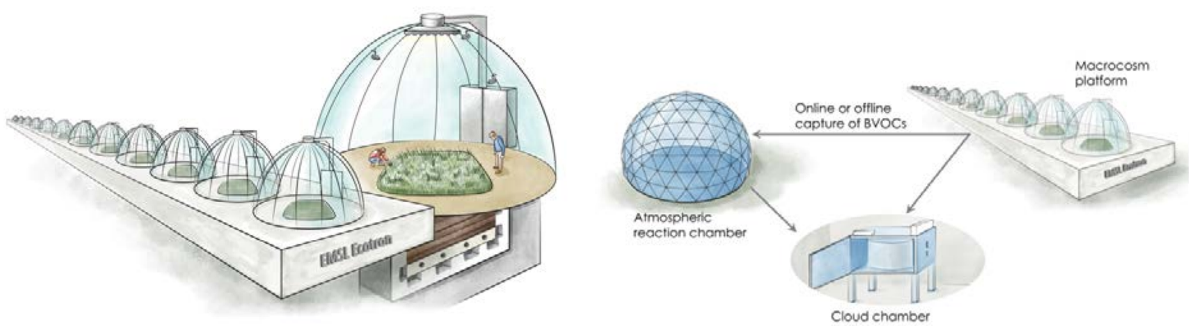

Figure 2. Schematics of the proposed EMSL Ecotron showing the macrocosm platform (left) and the integrated macrocosm and atmospheric reaction and cloud chambers (right). The inset in the left figure indicates the underground compartment with lysimeter and instrumentation.

3.2.1 Goal of the Workshop: *Christer Jansson*

Christer Jansson recommended the following questions to start the discussion:

- What is/should be the vision for an EMSL Ecotron?
- As an alternative to building an EMSL Ecotron, what capabilities exist elsewhere and what options does EMSL have in leveraging them?
- Is there likely to be a strong user demand for an EMSL Ecotron?

- What should be the operational format to maximize occupancy of the Ecotron?
- Is access to complementary meso- and microcosms important/critical?
- Is the value of linking an Ecotron to existing EMSL capabilities obvious?
- What are the obvious strengths, weaknesses, opportunities, and threats associated with establishing an EMSL Ecotron?

3.3 Presentations: Montpellier and Hasselt Ecotrons in Montpellier, France and Hasselt, Belgium: *Alex Milcu, Natalie Beenaerts*

Figure 3. The macrocosm platform at the Montpellier Ecotron.

Alex Milcu presented the CNRS-Montpellier Ecotron ([Ecotron-Montpellier]) consisting of 14 outdoor macrocosms, 18 outdoor mesocosms, and 13 indoor microcosms. The macrocosm platform with 14 dome-shaped units can accommodate growth systems up to a 5 m^2 growth area, 40 m^3 total air volume, and from 2-12 tons total soil weight. The ecosystems are set up in an integrated growth chamber and lysimeter configuration with 2 m soil depth. There are 12 experimental units along with two end units that serve to eliminate border/shadow effects. In addition to reconstructed ecosystems, the macrocosms have the ability to accept complete wide-bore cores (monoliths, 1.2-1.8 m diameter) that have been drilled from in situ experimental plots to sample an entire, intact ecosystem.

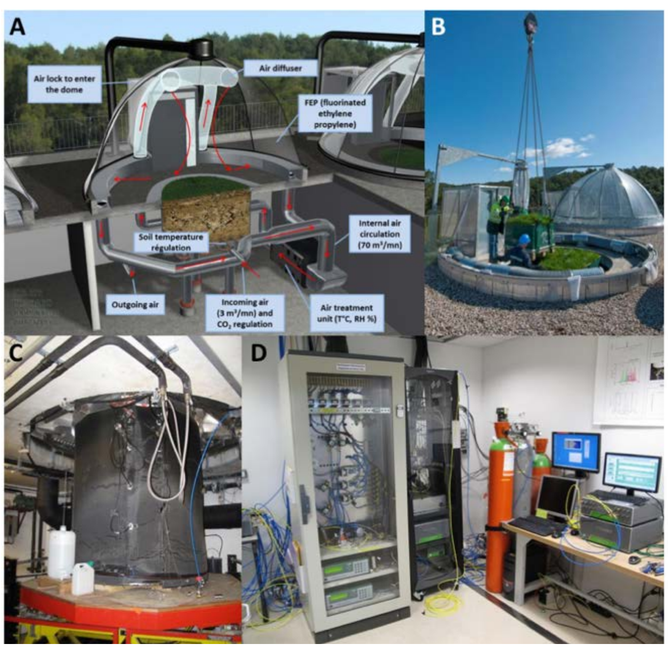

Figure 4. Ecotron macrocosm components at the Montpellier facility. A, Scheme describing components; B, Lysimeter insertion; C, Instrumented lysimeter; D, Gas and isotopes measurements laboratory.

The Ecotron macrocosm units have the flexibility to simulate a wide range of climatic conditions (including sub-zero degree °C temperatures) and CO_2 concentrations. Because of their dome-shaped fluorinated ethylene propylene film cover, which is transparent to greater than 95 percent of solar radiation, the macrocosm units receive realistic sunlight quality and intensity (greater than 2,000 µmols photons m^{-2} sec^{-1}) even at high distance from the soil. It is also possible to block the sun's radiation and use advanced light-emitting diode lighting arrays. If close enough to the soil level (less than 50 cm), the artificial light can deliver up to full sunlight.

Ecosystem processes at the Ecotrons are measured at high temporal resolution, in particular the automated online flux measurements of H_2O, CO_2, CH_4, and N_2O. A specific emphasis is put on isotopic techniques (^{13}C labeling of the organic matter and carbon dioxide ^{13}C

online measurements). Real time access to the environmental conditions of each unit and to the online measurements via internet allows authorized researchers to follow the experiment from any location. A staff (approximately eight research engineers and technicians) runs the infrastructure and secures the online measurements.

The mesocosm and microcosm units both measure 2 m^3 and 1 m^2 and are configured with or without lysimeters.

The Montpellier Ecotron is a European user facility and accepts proposals from countries inside and outside of Europe. The typical cost for a user on the macrocosm platform is €130K. Projects usually run for one year or longer. Since the inauguration in 2011, 29 projects have run on the macrocosm platform.

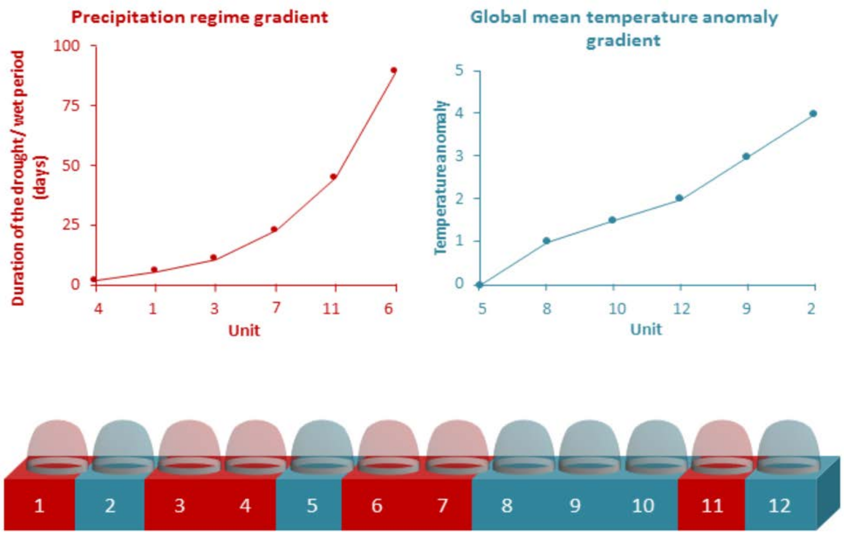

Figure 5. The experimental layout for the 2016-2020 project operating at the macrocosm platform of the Hasselt Ecotron.

The Ecotrons in Montpellier are part of larger European research infrastructures, such as Analysis and Experimentation on Ecosystems (AnaEE) and are user facilities with open calls for proposals, similar to EMSL.

Natalie Beenaerts described the macrocosm platform of the Ecotron at the University of Hasselt (Ecotron-Hasselt), which was constructed in 2016 with similar configuration and dimensions as the Ecotron in Montpellier. A major difference between the Hasselt and Montpellier platforms is that in Hasselt, a consortium of 16 principal investigators from different institutions and universities came together to decide on a 5-year project to study the effects of precipitation and temperature gradients along predicted future climate scenarios on a heathland ecosystem.

3.4 Presentation: SAPHIR-PLUS facility in Jülich, Germany: *Astrid Kindler-Scharr*

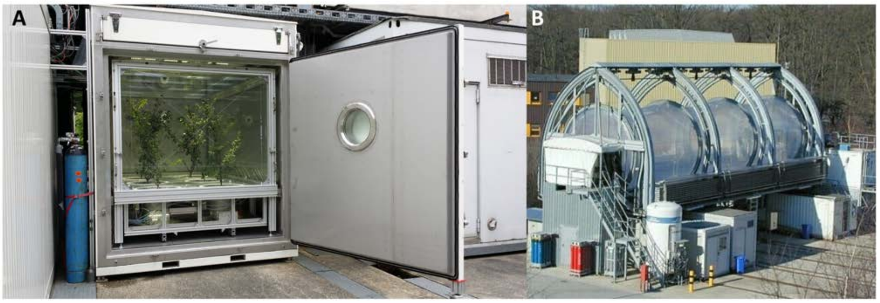

Figure 6. The SAPHIR-PLUS facility in Jülich, Germany.

Astrid Kindler-Scharr described SAPHIR-PLUS in Jülich, Germany, an atmosphere-simulation chamber linked to an environmentally-controlled dynamic (flow-through) plant chamber for investigations of BVOCs. Although the integration of the macrocosm platform with atmospheric reaction and chambers envisioned for an EMSL Ecotron differs significantly from the setup at the SAPHIR-PLUS facility, it was useful to learn about the requirements being considered when linking their plant chamber to the SAPHIR unit.

4.0 Discussion

The remainder of day one and the morning of day two was reserved for discussion. Christer Jansson had presented a list of questions that were used as an initial framework (Section 3.2.1). These questions were also sent to the participants ahead of the workshop. Jansson started day two with a list of topics of specific interest from day one and these formed the basis for much of the ensuing discussion. In the following subsections, the workshop discussion is organized thematically rather than in any chronological order.

4.1 Challenges with macrocosm Ecotrons

Major challenges operating the Montpellier and Hasselt Ecotrons are funding and personnel; both facilities seemed to be chronically under-funded and under-staffed. A list of specific problems follows:

- Cost and size. It was argued that the Ecotron macrocosms in Montpellier and Hasselt might be unnecessarily big. For example, running stable-isotope probing experiments has become very expensive and the costs for CO_2 scrubbing are prohibitive.
- Complexity. The experimental systems tend to become very complex; the project currently running in the Hasselt Ecotron relies on controlling seven parameters in concert and collecting approximately 184,000 data points daily. A specific bottleneck is the need for personnel to process massive data sets and generate models.
- Occupancy. For the macrocosm platform at the Montpellier Ecotron, which accepts projects based on an annual call for proposals, it is essential that the macrocosms do not sit idle for an extended period of time. To make sure there is full occupancy, projects that do not maximize the use of the macrocosm platform are given low priority. Also, in between user projects, other experiments requiring the macrocosm scale can be solicited. Still, full occupancy can, at times, be an issue.
- Downtime between experiments. Often when a new experiment is undertaken in the Montpellier macrocosms (e.g., new design or imported ecosystems), there is a downtime of approximately four months.
- Publications. Another issue relates to the number of publications resulting from the research. Owing to the long-term nature and complexity of the macrocosm projects, the frequency of publications is low compared to experiments carried out on a smaller scale, such as meso- or microcosm studies. Since 2011, the Montpellier Ecotron has generated 12 publications from macrocosm projects.

Many of the same issues with under-funding and system complexity that were discussed for the Ecotrons appear to be true for the four indoor EcoCELLS macrocosms at the DRI and with Biosphere 2.

4.2 The role of macrocosms in ecosystem science

In considering experimental systems for addressing environmental science questions, there is usually a trade-off between scale and environmental relevance. Small systems, like plant growth chambers or microcosms, permit highly controlled environmental setups and advanced measurements of many parameters but produce results that are often of little relevance to the complex and stochastic nature of an outdoor field site, be it a native ecosystem or a cropping system.

On the other hand, instrumented field sites and/or field sites monitored by drones or gantry systems exhibit high environmental relevance but do not allow the same degree of sophistication for environmental controls or measurements. Various intermediate-scale systems, such as mesocosms and macrocosms, with or without lysimeters and with varying degrees of sophistication, occupy the middle ground between these boundary systems. The macrocosm platforms at the Montpellier and Hasselt Ecotrons fill a specific gap in this scale-relevance gradient in that they are a size that can replicate an outdoor system and also allow highly advanced environmental controls and measurements. Another important feature is the dome-shaped macrocosm units in Montpellier and Hasselt, which are covered with a transparent film that allows greater than 95 percent of natural sunlight into the ecosystems. It is documented that not only photosynthesis, but other plant processes are significantly different between natural sunlight intensities and spectra and artificial lighting.

It was readily realized that the different scales (micro-, meso-, and macrocosm) all fill important roles in ecosystem science, and they are used to answer different questions. The Ecotron macrocosm platform is focused on studying ecosystem processes such as evapotranspiration, ecosystem carbon fluxes, greenhouse trace gases, and isotopic tracing and fractionation. It was suggested that to accurately measure ecosystem processes, such as reactive transport, gas fluxes, and drought responses, requires macrocosm scales. Also, experiments on large plants, such as sorghum or switchgrass, would benefit from macrocosms.

A point was made that ecosystems are overwhelmingly complex adaptive systems. A cornerstone in comprehending such complexity lies in understanding and modeling how the many different components and processes of the ecosystem inform emergent properties of the system. Adaptive modeling of ecosystem functions and responses is greatly facilitated by experimental systems of a scale and setup that satisfactorily represent the outdoor environment and with a sophistication that allows tight control and simulation of environmental variables.

There were contrasting views regarding reproducibility in ecosystem experiments. Some participants believe the scientific community has a great need for improved reproducibility and that it will benefit from smaller but many systems where experiments are replicated as opposed to fewer and larger systems (e.g., a large number of mesocosm-scale systems rather than a smaller number of macrocosms). Alex Milcu made this point as well during his seminar one day following the workshop. Other participants believe information about reproducibility in large-scale experiments such as macrocosms can be obtained indirectly from running gradients, as illustrated by the project operating the Hasselt Ecotron (Figure 4). One participant suggested EMSL go for “bigger and fewer systems.”

4.3 Opportunities and challenges with an EMSL Ecotron

It was generally agreed that the proximity of an Ecotron to EMSL would add immense depth to the EMSL project overall and, in and of itself, would make this facility world unique. Clearly, integrating existing EMSL capabilities with the Ecotron would permit and spur new and exciting science. The addition of atmospheric reaction and cloud chambers to the macrocosms was viewed as novel, holding great promise for an EMSL Ecotron to position PNNL at the forefront in environmental research. It was also suggested that an EMSL Ecotron could serve as testbeds for genome-edited plants and microbial consortia and for “lunar greenhouses” or bioregenerative life support systems onboard space stations.

There were concerns, however, that an EMSL Ecotron would serve only a few users, tie up EMSL staff, and reduce the accessibility of EMSL capabilities to the broader user community.

There were also concerns that scientist time rather than instrument time is already a bottleneck at EMSL, which has been discussed during yearly EMSL UEC meetings. Thus, if adequate funding could be secured that included additional scientific staff, there would be little impact on the current level of accessibility for users. An EMSL Ecotron would also bring in new users.

Related comments regarding the user-based community were how EMSL would have to change from single principal investigators to multiple investigators on user proposals. One option would be to view an EMSL Ecotron more like a BER facility than an EMSL capability and run research campaigns similar to the arrangements between the U.S. Department of Energy's (DOE) Office of Science Atmospheric System Research program and Atmospheric Radiation Measurements user facility. An alternative suggestion was to operate an EMSL Ecotron similar to the format of the Hasselt Ecotron, where a consortium of investigators agrees on a long-term (five years) project following the progression of the same ecosystem in parallel under different environmental conditions.

While the atmospheric chamber add-on to the macrocosm platform was considered intriguing and strategically important, it was also met with trepidation because PNNL has not worked with plant-derived BVOCs at any significant scale. It was commented that this feature of the Ecotron was not well thought out. Furthermore, material in the macrocosms, including the fluorinated ethylene propylene film cover, would need nonreactive surfaces to avoid contributing to volatile organic compounds (VOCs). Conceivably, this problem could be circumvented by subtracting VOCs from macrocosm units not containing experimental specimens.

Cost was another concern for establishing and operating an EMSL Ecotron. Based on experience from the Montpellier and Hasselt Ecotrons and the proposed configuration of an EMSL Ecotron, the costs for an EMSL Ecotron can be summarized as follows:

- Capital installation: $9M
- Maintenance (five full-time staff): $1.9M per year
- Operational costs: $170K per year. Note: User fees cover operational costs for the Montpellier Ecotron.

Some attendees indicated these costs for an EMSL capability exceeded a reasonable proposal to BER. While others, particularly those familiar with EMSL, found the installation cost to be quite moderate and well in line with other EMSL capabilities. Adding the annual maintenance and operational costs would make an EMSL Ecotron substantially higher than past projects of any other EMSL capabilities.

There was a suggestion to apply for a National Science Foundation infrastructure grant. However, this idea was discounted because the National Science Foundation will not fund a DOE user facility, and it is unlikely that an academic institution would let the bulk of a grant go to a capability at PNNL.

A partnership possibility with other entities, such as the EcoPOD group at LBNL or Frits Went Laboratory at the DRI that contains the EcoCELL platform, was discussed. There was mutual interest in partnerships. However, no financial mechanisms are in place to support such arrangements.

There was a question regarding how much, if any, of the EMSL Ecotron concept had been disclosed to BER. Jansson explained that the idea of an EMSL Ecotron was mentioned to Paul

Bayer and other BER project managers in January 2017 during a presentation about PNNL's plant-biology capabilities. At that time, Bayer's response was positive, and he suggested a closer tie and collaboration with the Montpelier Ecotron, which has since been formed. A more detailed discussion of the EMSL Ecotron concept was held with BER during a Skype conference in February 2019. Kirsten Hofmockel, as the acting EMSL CSO, discussed the concept in her presentation at the GSP meeting in February 2019.

4.4 Summary of impressions from European Ecotron presentations

It was evident from Alex Milcu and Natalie Beenaerts, the Directors for the Montpellier and Hasselt Ecotron, respectively, that they strongly felt their macrocosm platforms fill a critical role in ecosystem science and in being able to predict the effects of climate change on ecosystem functions and responses. At the same time, they agreed that managing the macrocosm platforms is quite challenging ("a headache") and that funding is a constant problem. Jay Arnone from DRI and Laura Meredith from Biosphere 2 echoed this sentiment. Alex Milcu was also clear that, were he to build another macrocosm platform today, the units would be somewhat smaller in scale (compared to the present Montpellier Ecotron) to be more manageable. He suggested that a surface area of 2 m^2 and a soil depth of 1.5 m, rather than 5 m^2 and 2 m, respectively, would still replicate the outdoor ecosystem.

4.5 Summary of UEC comments

The UEC members did not reach a consensus on whether or not to recommend an EMSL Ecotron. However, they agreed that the proposed EMSL Ecotron, with image-based phenotyping, atmospheric reaction and cloud chambers, and EMSL's omics capabilities would represent a unique and exceptional resource for EMSL users, the scientific community at large, PNNL and EMSL, and DOE. This enthusiasm was countered with concerns for costs and reduced availability for other EMSL capabilities. There was also a question regarding a paradigm shift for conducting future user proposals and projects.

There was a general feeling that continued planning and research are needed. Furthermore, a sustainability plan and cost-benefit analysis are needed before decisions are made. It was also suggested to vet the EMSL Ecotron concept at the EMSL 2019 Integration meeting in October (Appendix B).

After considering a draft version of the workshop report, the attending UEC members provided a post-workshop summary of the EMSL Ecotron Workshop (Appendix C).

5.0 Conclusion

The workshop was held in a very open, positive, and candid environment. The invited participants provided wide-ranging, informed, and highly valuable comments. Furthermore, the participants, including the staff at PNNL, were engaged in lively but structured discussions.

The discussion described in Section 4 resulted in several conclusions:

- An EMSL Ecotron is a bold endeavor that would potentially put PNNL and EMSL at the forefront of multiscale and multidisciplinary ecosystem science and be a focal resource for the scientific community.
- Integrated with existing EMSL capabilities, an EMSL Ecotron would be an extraordinary powerful resource for the EMSL user community.
- Launching an EMSL Ecotron would be a risky undertaking given the challenges reported for the Montpellier and Hasselt Ecotrons, as well as for the DRI EcoCELLs and Biosphere 2.
- An EMSL Ecotron would be disruptive to the procedural format for EMSL user proposals and require collaborative multi-investigator and long-term projects.
- An EMSL Ecotron would require sustained funding to cover operational costs in addition to increased BER funding for the overall EMSL operations.
- A thorough cost-benefit analysis and sustainability plan need to be developed to ascertain maximum utilization and occupancy of an EMSL Ecotron.
- The macrocosm units of an EMSL Ecotron should be smaller and nimbler than the ones in Montpellier and Hasselt while at the same time be a scale large enough to serve as proxies for outdoor ecosystems.
- The possibility of partnering with existing macrocosm facilities in the U.S., such as the DRI EcoCELLS, should be explored.

6.0 Next steps

- Digest and discuss the EMSL Ecotron Workshop Report as part of a vetting process within EMSL and PNNL.
- Continue discussions and meetings with the UEC.
- Make a go/no-go decision whether or not to pursue a modified EMSL Ecotron concept.

Appendix A EMSL Ecotron Workshop May 20-21, 2019

AGENDA

Monday, May 20, 2019				Location
7:30 am	Badging			Discovery Hall/EMSL
8:30 am	Welcome	Christer Jansson	EMSL	EMSL Board Room
8:50 am	Introduce new EMSL Director, Douglas Mans	Christer Jansson	EMSL	EMSL Board Room
9:00 am	EMSL Presentation	Kirsten Hofmockel	EMSL	EMSL Board Room
9:30 am	EMSL Ecotron Proposal & Vision	Christer Jansson	EMSL	EMSL Board Room
10:00 am	Break			EMSL Board Room
10:30 am	Montpellier Ecotron Presentation	Alexander Milcu	Ecotron, Montpellier, France	EMSL Board Room
11:00 am	Hasselt Ecotron Presentation	Natalie Beenaerts	University of Hasselt, Hasselt, Belgium	EMSL Board Room
11:30 am	Discussion			EMSL Board Room
12:00 – 1:00 pm	Working Lunch – Continued Discussion			EMSL Board Room

1:00 pm	SAPHIR-PLUS Presentation	Astrid Kiendler-Scharr (Skype)	Jülich Research Center, Jülich, Germany	EMSL Board Room
1:30 pm	Discussion			EMSL Board Room
2:30 pm	Photo Shoot & Break			EMSL Lobby
3:00 pm	Discussion			EMSL Board Room
4:30 pm	Wrap Up			EMSL Board Room
6:00 – 7:30 pm	No Host Dinner			LuLu's
Tuesday, May 21, 2019				**Location**
8:00 am	Follow-up Discussions			EMSL Board Room
11:00 am	EMSL Tour	Mark Bowden	EMSL	EMSL
12:00 – 1:00 pm	No Host Lunch			Venezia

Appendix B
Post-Workshop Summary of Discussion at the EMSL 2019 Integration Meeting

The Environmental Molecular Sciences Laboratory (EMSL) Ecotron concept was briefly presented and discussed during the EMSL 2019 Integration meeting on October 8, 2019. While participants noted that an EMSL Ecotron would offer world-unique opportunities in environmental sciences, they cautioned that the demand for such a capability would likely be modest.

Appendix C
Post-Workshop Summary by the EMSL User Executive Committee

This appendix summarizes feedback from the Environmental Molecular Sciences Laboratory (EMSL) User Executive Committee members who attended the EMSL Ecotron Workshop and subsequently reviewed a draft workshop report.

While there was consensus that there is a need for a U.S. based Ecotron research facility, there were mixed opinions whether such a large investment would have long-term benefits for the broader user community. Furthermore, there were mixed opinions whether such a facility could be financially sustainable in years to come. It will be interesting to see how the concept is received during the 2020 EMSL Integration Meeting, October 6–8.

The committee suspects that a substantial investment will be needed to build and sustain an EMSL Ecotron during operation. There was a strong sentiment that this investment should not cut into the existing EMSL budget. Additionally, such a facility would require direct funding, such as a line item in the federal budget along the lines of synchrotrons or other large user facilities that require significant capital and a long-term financial commitment to staffing. It was evident from workshop presentations on the European macrocosm Ecotrons (with sentiments echoed by the representatives from the Desert Research Institute and Biosphere 2) that their platforms are struggling with challenges associated with managing these complex facilities and continuing financial support.

Favorably, the committee felt the concept of a large macro-scale EMSL Ecotron integrated with reactive atmosphere chambers and/or cloud chambers was truly innovative. Additionally, integrating the terrestrial biological, chemical, and physical processes in such a system could elevate the possibilities of new science discovery.

Less favorably, the committee felt the reaction chambers and cloud chambers to study atmospheric processes and biological volatile organic compounds would be quite challenging, in part because of the constraint on nonreactive materials in all of the chambers. Additionally, EMSL's lack of demonstrated expertise in the operation of these kinds of chambers warrants caution for adding any of these capabilities.

There seemed to be a consensus that existing systems could benefit from a broader and deeper "feeder" system of micro- and mesoscale systems because a new macro-scale system would face the same problems as those that already exist. It seemed unclear whether the same science benefits could be achieved by integrating terrestrial and atmospheric processes into the smaller study systems. The consensus was an EMSL Ecotron based on a larger number of smaller scale systems, rather than fewer larger-scale systems, would offer the user community more access, leverage the existing EMSL analytical capabilities to a greater extent, and result in more papers and user appreciation. This approach could lead to a federally funded and supported Ecotron at a larger scale to better understand the interface of climate, plant, and atmospheric science.

A partnership with an existing facility might be an initial step for EMSL to gauge cost and effort. This proposed partnership might also test the EMSL users' responsiveness to a new platform and evaluate how they would adapt to an approach requiring team-based science.

The committee's biggest concern was the user-based community's reduced involvement if EMSL invested solely in a scaled-up macrocosm system. As a case in point, the Montpellier Ecotron Facility typically operates its macrocosm systems for one year or longer and over the last eight years, it has run 29 projects. These 29 projects translate to approximately four users per year—a number (four users per year) that is considered extremely low. EMSL management would have to be proactive in creating scientific consortia to make this practical and more encompassing of the user community and their science needs.

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