A RESEARCH STUDY OF RELEVANT BIOMIMETIC PURSUITS

2021-2022 DEEP DIVE

BIOMIMICRY ON THE RAY

PREPARED AND PRESENTED BY

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THE RAY

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"Our planet is telling us a story. Vital connections have been severed between human beings and nature, within nature itself, and between people, religions, governments, and commerce. This disconnection is the origin of the climate crisis; it is the very root—and it is where we discover solutions and actions that can engage all people, regardless of income, race, gender, or belief.

The earth's biological decline is how it adapts to what we are doing. Nature never makes a mistake. We do. The earth will come back to life no matter what. Nations, peoples, and cultures may not. If putting the future of life at the heart of everything we do is not central to our purpose and destiny, why are we here?"

PAUL HAWKEN

REGENERATION: ENDING THE CLIMATE CRISIS IN ONE GENERATION (2021)

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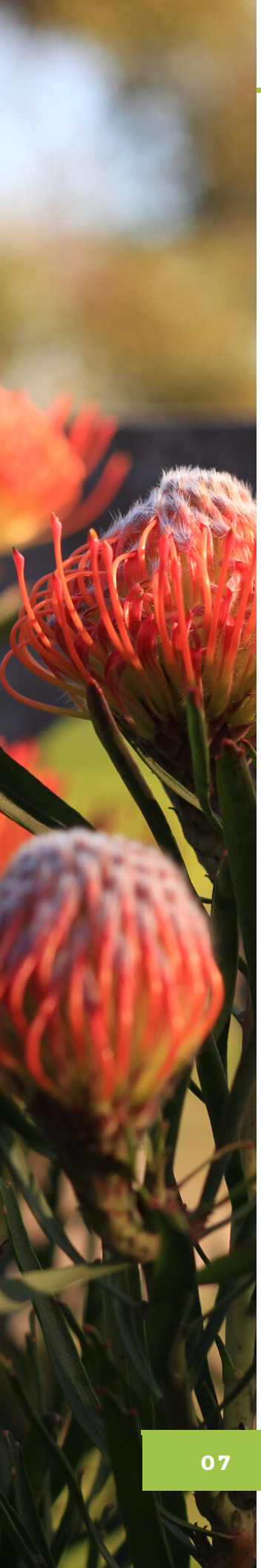
SECTION I

OVERVIEW

The following overview includes the March-Dec 2021 Biomimicry on The Ray project summary, a reflection of The Ray's goals and how biomimicry can amplify and elevate these goals. This section provides a summary of Biomimicry on The Ray's scope of work, the identified project goals and a summary of The Ray's 2022 Biomimicry Literacy Training.

"The truth is, natural organisms have managed to do everything we want to do without guzzling fossil fuels, polluting the planet or mortgaging the future."

- Janine Benyus



A. PROJECT SUMMARY

The Ray is a nonprofit organization dedicated to reimagining the way we connect our communities, our lives, and our world. The Ray serves as a proving ground for the evolving ideas and technologies that will transform the transportation infrastructure of the future.

Biomimicry has been identified as a key driver to aid in this mission. Biomimicry on The Ray is a sustainability initiative that serves to generate a comprehensive understanding of how biomimicry can advance the regenerative design mission and goals of The Ray. The aim of this initiative is to present bio-inspired ideas that align with The Ray's vision, to the relevant stakeholders for consideration of implementation.

The following document highlights biomimicry methodologies, strategies, tools, products, services, and offerings that directly aid in achieving The Ray's current goals, as stated in the Innovia Technologies "Building The Ray's Roadmap for 2020- 2025" Report and the May 2021 Fox Advancement's "Vision Impact Alignment" Document. The following report intends to serve as a guide to familiarizing the Ray stakeholders with biomimicry design pursuits that are highly relevant and require minimal resource input (time, money, energy and staff) from the Ray that align with the visioning documents guiding The Ray. This report is a living document with multiple links to diverse interactive sources, each uniquely relevant to the data it showcases. As a result, this document introduces new digital tools to The Ray. It is through the development of this research summary report and the creation of an internal stakeholder biomimicry literacy curriculum that we conclude the 2021 research phase of this project.

PROBLEM STATEMENT

Regenerative and sustainable design innovation is deeply driven by the biomimicry mindset, though it is seldom considered or understood by entities aiming to design regeneratively. This project will catalyze the adoption of biomimicry thinking by leveraging The Ray's innovation testbed to demonstrate the effectiveness of utilizing biomimicry when tackling complex systems redesign, such as highway development in the transportation and mobility sector.

B. BIOMIMICRY ON THE RAY

THE PURPOSE OF THE RAY

The Ray is a legacy project initiated by Harriet Langford to honor the late Ray C. Anderson, a pioneer of sustainability in commerce. Ray revolutionized the green business industry to create a world that is healthy, thriving, and safe for tomorrow's child. The stretch of highway, in his name, should be no less. The transportation industry is often exclusively associated with fossil fuels and emission production. The Ray aims to revolutionize this extractive identity and bring forward a picture of pragmatic hope that is scalable and replicable to create a brighter future for transportation and mobility.

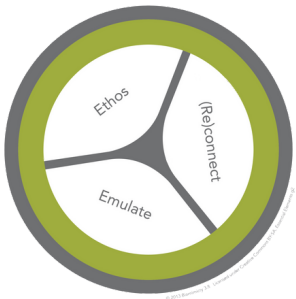
HOW DOES THE RAY DO IT?

By reinventing standard approaches to transportation, The Ray is revolutionizing the regenerative capabilities of highways that have been ignored for decades. Taking on the roles of innovator, evangelist, and capacity builder, The Ray seeks to undertake regenerative transportation design initiatives. The Ray is setting an example for how our world could function, by demonstrating tangible examples of regenerative highway innovation on its 18 mile stretch. Transportation of people, products, energy, accessibility, and connectivity can all be reimagined in regenerative ways. By setting an example in transportation, The Ray is changing the way our world functions.

WHAT IS BIOMIMICRY?

Biomimicry is innovation inspired by nature. It is a design methodology that formalizes learning from nature's nearly 4 billion years of evolutionary research and development. Biomimicry is about shifting our perceived role of nature, from a warehouse of resources or a sink for our wastes, to a library of solutions, leading to the regenerative paradigm that we urgently need to embrace. Biomimicry as a formal practice leverages well researched bodies of scientific knowledge to build "beyond sustainable" solutions. Biomimicry consists of three essential elements:

EMULATING nature
Biomimicry is the act of reproducing the function or action of living organisms structures, processes and ecological systems



ETHOS of design
Biomimicry prioritizes emulating nature in a way that aligns with sustainable and regenerative design. Designing like nature to fit into nature. This includes a sustainable, restorative and regenerative mindset when looking to the natural world to guide design.

RECONNECTION to the natural world
Biomimicry acknowledges the importance of reconnecting with nature in ways that have been lost in most modern societies. By redefining our relationship with nature, we begin realizing we are not separate from nature, and that our current practices have played a huge role in facilitating this disconnection.

HOW DOES BIOMIMICRY ELEVATE THE RAY'S MISSION?

When considering sustainable design, challenges of a lack of support and guidance are apparent. Our generation is pioneering the sustainability movement. We often hit limits of our own creative capacity as we are products of the mindset that created these problems in the first place. However, when seeking models to emulate, biomimicry reminds us that nature is the epitome of sustainability and regeneration.

Nature provides us a creative lens with which we can find millions of innovative solutions to our regeneration challenges. By looking to nature as a mentor, a measure and a model for systems level revitalization of highway transportation, mobility and beyond, The Ray can tie our designs back into the healthy functioning natural systems of the planet.

WHY IS BIOMIMICRY A CRUCIAL LENSING TOOL?

Why design like nature? Because we can create conditions conducive to life, just like nature does. Over a period of nearly four billion years since life began, the process of evolution has transformed earth into a living lab of experiments to see what works and what doesn't. As Janine Benyus says "After 3.8 billion years of research and development, our failures are our fossils and *what surrounds us* is the secret to our survival." Over time this has resulted in highly sophisticated forms, processes, and living systems, far out-functioning linear, exploitative and inefficient heat, beat, and treat design methods.

> "For a resilient, durable and sustainable future for human society, we need to repurpose, reinvent, redesign, remake and recover our human made world so that our built environment is seamlessly biointegrated with nature and functions synergistically with it."
>
> - Ken Yeang

VARIOUS WAYS OF EMULATING NATURE

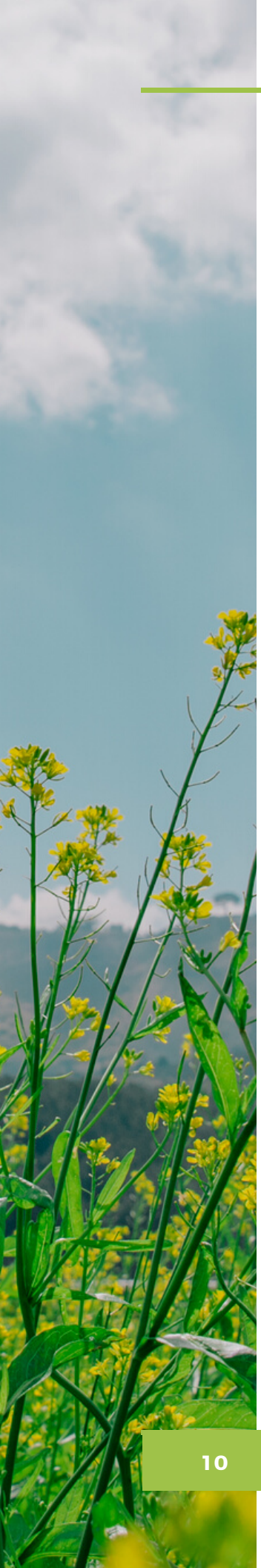
Nature can be emulated in multiple ways. Designs can mimic physical natural forms -- natural structures and shapes to perform specific functionality, like the emulation of the form of the Kingfisher bird beak to increase efficiency and eliminate sonic booms of the Shinkansen Bullet Train.

Designs can emulate natural processes, such as the current redesign of building materials to act as carbon sinks inspired by the carbon sequestration process of coral building their reefs, or improving the efficiency of solar energy capture by emulating the process of photosynthesis used by plants.

Designs can also emulate ecosystems, like developing a symbiotic economy within an eco-industrial park system in Kalundborg, Denmark such that the energy, materials, and water left over from one process are used as input for the next. Heat released by electricity generation is recaptured for district heating, greenhouses and fish ponds. Ash output becomes cement and aggregate input. Steam output becomes biotechnology and pharmaceutical plant input. As the eco-industrial park matures into a circular economy, diversity and complexity increase, amplifying net benefit for all entities.

THE GRADIENT OF LITERAL TO CONCEPTUAL EMULATION

Nature can guide both literal, tangible designs such as those of products, as well as conceptual, intangible designs such as social structures of governance. Whether designing an entire eco-industrial park, or designing a business's organizational structure, natural principles can be incredible guides for regenerative design.



C. SCOPE OF WORK 2021

The following documentation summarizes the strategic planning, processes, and procedures currently in place at The Ray, in addition to strategic scoping information collected during this research initiative that has guided the research summary report.

OUR PROCESS

A three month intensive scoping phase was conducted from March - May 2021. The scoping procedures included internal and external stakeholder interviews, review of organizational publications, featured articles and strategic planning documentation, and synthesis of data collected that guided the project scope and areas of focus of this research summary report.

The detailed scoping process can be accessed here.
Documents of alignment include but are not limited to:

- July 2018 Innovia Technologies "Technologies for The Ray 2015-2020" Report
- September 2020 Innovia Technologies "Building The Ray's Roadmap for 2020-2025" Report
- May 2021 Fox Advancement "Vision Impact Alignment" Report
    - The Ray's featured articles and publications

Key areas to note include technology guidelines in the 2020-2025 Innovia Tech Report, The pillars sections (The Innovator, Evangelist, and Capacity Builder), Key Areas of Focus section, and the Programmatic Lens section from the Fox Advancement Vision Impact Alignment Report

- The biomimicry team conducted various interviews with key stakeholders and staff at The Ray. Interviews were intended to:
    - Identify stakeholder knowledge of, and interest in biomimicry
    - Understand the goals, aspirations, and mission of The Ray and its stakeholders
    - Identify biomimicry application spaces relevant to The Ray's vision
    - Align identified biomimicry pursuits with strategic plans of The Ray

- The aforementioned information was synthesized into a Scope of Work that was delivered in May 2021. It was then confirmed as the viable path forward with feedback included from The Ray staff. The following report is a reflection of the execution of the agreed upon statement of work.

D. PROJECT GOALS

SUMMARY OF GOALS AS STATED IN THE SCOPE OF WORK

Note: The order of these goals have been adjusted to reflect cohesive report delivery

GOAL I. STAKEHOLDER BIOMIMICRY LITERACY TRAINING

By developing streamlined, scalable and replicable biomimicry literacy training content specific for The Ray's core staff and external stakeholders, we aim to clarify and facilitate the level of knowledge innovators in similar and diverse sectors require for the successful adoption of biomimicry methodologies.

GOAL II. IDENTIFY EXISTING APPLIED BIOMIMICRY/BIO-INSPIRED TECHNOLOGIES, OFFERINGS & SERVICES

Goal II.a Technologies

The team will identify currently existing biomimetic designs that aid in accomplishing the stated goals of The Ray; reflected in the 2020-2025 vision document and the May 2021 Fox Advancement Strategic Planning Document, The Ray can explore serving as a testbed for promising existing bio-inspired technologies/services.

Goal II.b Biomimicry practitioners/services/offerings

The team will perform extensive outreach initiatives to identify all currently existing biomimicry services and offerings that will aid in the accomplishment of The Ray's specified goals. We will develop an ecosystem of bio-inspired offerings that encompass all currently underway biomimicry services. This initiative will allow those who are currently offering relevant services the opportunity to demonstrate the service's success. This will advance The Ray's goals while simultaneously serving as a testbed for existing biomimicry offerings.

GOAL III. DEMONSTRATE DESIGN SOLUTIONS BY APPLYING BIOMIMICRY DESIGN METHODOLOGY TO THE RAY'S CHALLENGES AND GOALS

Demonstrate possible technology, process, system, or social innovation development by applying the biomimicry design thinking process to multiple challenges The Ray aims to solve, including but not limited to:

Zero Carbon via:

- Renewable Energy
- Off-grid EV Charging / Electric (Electrification) Future of Freight (Hydrogen, platoon, inductive)
- Ecosystem Services/Sequestration
- Materials/ Bio-Materials

Zero Deaths via:

- Smart Highways (road dot, safety check, lighting) Infrastructure Automated Key functions (rapid response drones)
- Vegetation Management
- Wildlife Corridors

Zero Waste/Pollution via:

- Remediating the Environment
- Pollution Sense/abatement (Gas-sensing VTOL) Infrastructure (Biomaterials)

Education via:

- Internal - The Ray employees (train the trainers)
- External Stakeholders (Business)
- External Stakeholders (Non- Business)
- General communications/marketing campaign - Comms Director - articles, videos, etc. (The Ray audience)

Supporting Wildlife & Biodiversity (Reduce wildlife impact and maintenance):

- Support of Landscape architecture projects "Nature technology"
- Remediate environment (environment monitor, bioswale)
- Land maintenance (robot mowers)
- Reconnect
- Ecosystem Services/ Project Positive
- Involvement BMY wildlife corridors, pollinator habitats

GOAL IV. PROVIDE A COMPREHENSIVE BIOMIMICRY ANALYSIS FOR REGENERATIVE ADVANCEMENTS ON THE RAY.

Leverage life's principles analysis, genius of biome reports, bio brainstorm reports, and apply the biomimicry design thinking methodology to currently existing technologies, processes, and systems on The Ray

GOAL V. LEVERAGE BIOMIMICRY METHODOLOGIES TO IMPROVE SOCIAL INNOVATION INITIATIVES AT THE RAY

Apply biomimicry methodologies conceptually by looking at characteristics of natural systems and how they can influence improvements in social innovation initiatives, including but not limited to:

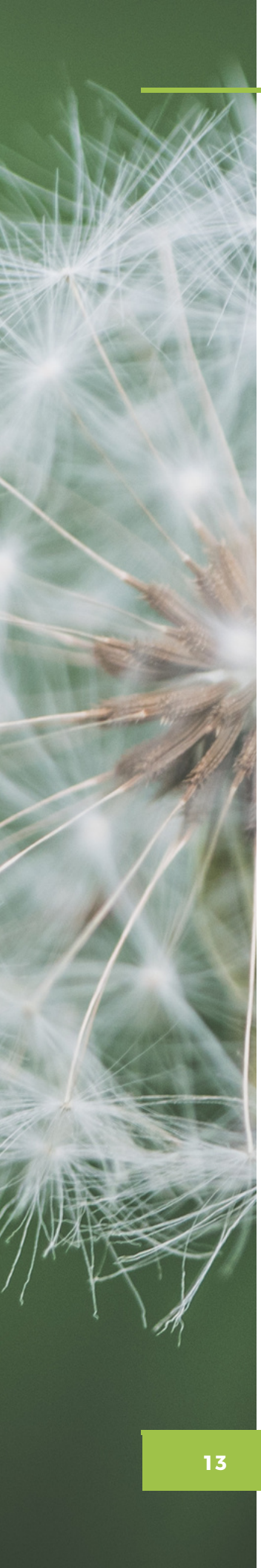
- Local, regional, and national business participation
- Engaging the communities of LaGrange, Ga and West Point, GA
- Identifying reconnect opportunities
- Internal organizational development
- Local, regional, and national scalability strategy (for all replicable initiatives)
- Law and policy restrictions, constraints and opportunities (Shannon Sweeney)
- Education, cultural shift, and perspective shift
- Social justice - equity, diversity, and inclusion - (i.e., Mobility XX, etc.)

GOAL VI. EXTERNAL STAKEHOLDER BIOMIMICRY COMMUNICATION

Develop a comprehensive biomimicry communications plan that incorporates understandable and easily digestible highlights, relevant news updates, and publications of applied biomimicry in transportation and mobility.

GOAL VII. IDENTIFY THE FEASIBILITY OF IMPLEMENTING EACH SUGGESTED BIOMIMICRY PURSUIT

Provide feasibility information regarding any suggestions put forth in the biomimicry implementation pursuits document including but not limited to time requirements, budget estimates, resource allocation, and potential legal restrictions.



E. STAKEHOLDER LITERACY TRAINING

(ALIGNS WITH GOAL I: STAKEHOLDER BIOMIMICRY LITERACY TRAINING)

By developing streamlined, scalable and replicable biomimicry literacy training content specific for The Ray's core staff and external stakeholders, we aim to clarify and facilitate the level of knowledge innovators in similar and diverse sectors require for the successful adoption of biomimicry methodologies.

Goals of the Training are outlined *here* in sheet 1.

TRAINING OVERVIEW

Instructor: Deborah (Deb) Bidwell (bidwelld@cofc.edu) assisted by McCall Langford (mccall.langford@gmail.com) & Asha Singhal (asha@hybridfutures.de)

The 15 week training will be facilitated synchronously online using Zoom on Fridays from February 4th - May 27, 2022 from 4:00pm - 5:30pm Eastern. Fifteen classes are scheduled. Class will not be held on Friday, April 15th. A one-week cushion has been added to the schedule to accommodate scheduling flexibility, if required. Course resources will be made available through a shared google drive. Two reference textbooks are provided: Dayna Baumeister's Biomimicry Resource Handbook, and Erin Rovalo's iSites Workbook. Each week's lesson is summarized in handy biomimicry resource cards, for convenience and future reference. There are no required readings or assignments. The group learning community will be co-created. The instructor plays a facilitation role in helping the team get to know, trust and collaborate with one another. Each member of the training is invited to participate in an inclusive, dynamic and engaging learning experience. Participants are requested to attend class from a location that allows them to actively focus, keep video cameras on, join discussions and access nature.

Training Schedule can be accessed *here* in Sheet 2.

SUCCESS METRICS OF THE TRAININGS

Anonymous pre- and post- Qualtrics surveys will collect entry and exit data to assess participant growth in biomimicry literacy in three areas.

- Proficiency at describing biomimicry and giving examples applicable to The Ray
- Familiarity with commonly used biomimicry tools
- Capacity to gauge the potential value biomimicry offers The Ray

An invitation to provide direct feedback is built into the conclusion of the course.

SECTION II

MAPPING OUT EXISTING BIOMIMICRY OFFERINGS

ALIGNS WITH GOAL II. IDENTIFY EXISTING APPLIED BIOMIMICRY/BIO-INSPIRED TECHNOLOGIES, OFFERINGS & SERVICES

a. The team will identify currently existing biomimetic designs that aid in accomplishing the stated goals of The Ray. The Ray can serve as a testbed for promising existing bio-inspired technology/services.

b. The team will perform extensive outreach initiatives to identify all currently existing biomimicry services and offers that will aid in the accomplishment of The Ray's specified goals. We will develop an ecosystem of bio-inspired offerings that encompass all currently underway biomimicry offerings. This initiative will allow a mutualistic relationship between the service providers and The Ray which can serve as a testbed for existing biomimicry offerings.

A. EXISTING BIO-INSPIRED TECHNOLOGIES

(ALIGNS WITH GOAL II A. IDENTIFY EXISTING APPLIED BIOMIMICRY, BIO-INSPIRED TECHNOLOGIES)

The following information reflects existing biomimetic technologies that aid in accomplishing current goals of The Ray Highway. The initial research for each technology included seeking out basic information (developer, brief description of the tech, relevance case for The Ray and contact information). This has been followed by initial engagement with their respective development teams for market research to identify initial feasibility (market readiness, price point. etc.) which is currently in progress. The technologies have been classified according to their primary impact focus in zero carbon, zero deaths, and zero waste categories. All technologies have been further tagged with themes including but not limited to agriculture, automation/sensors, bio-materials, ecological performance standards, environmental remediation, infrastructure, land management, renewables/solar/energy, safety, UAVs, and V2X communication.

A graphical map of the technologies along with their details can be accessed *here.*
The information is also captured in a master spreadsheet that can be accessed *here*.

There is an opportunity to initiate an existing bio-inspired technologies pipeline to track and monitor the current bio-inspired transportation and mobility market. If pursued, the pipeline could expand on the snapshot of data presented in this report. The pipeline should continue to track:

- Identified technology's current market readiness, technology's price point, level of interest in installation within The Ray, and legal feasibility for installation.
- Primary scientific publications that feature bio-inspired research relevant to solving identified transportation and mobility challenges, tracked over time, to determine what theoretical designs have been conceptualized. Their market readiness can be tracked using standardized market readiness level tracking (0) Perceived Need (1) Notional Value Proposition (2)Notional Customer Characterisation (3) Customer Discovery (4)Low-Fi MVP Design (5)Low-Fi MVP Campaign (6) Revalidate Solution and Model (7) High Fidelity MVP Campaign (8)Validate Model With MVP Results (9) Go To Market Decision

B. EXISTING BIO-INSPIRED SERVICES/ OFFERINGS/ CONSULTANTS

(ALIGNS WITH GOAL II B. IDENTIFY EXISTING APPLIED BIOMIMICRY, BIO-INSPIRED PRACTITIONERS/SERVICES/OFFERINGS)

A large global community of individuals and organizations specializing in various bio-inspired design fields have been identified, each with their own niche. Potential project pursuits relevant to The Ray have been identified as well. This portion of documentation provides The Ray with a comprehensive list of biomimicry practitioners and their respective project pursuits of relevance.

A comprehensive outreach initiative engaging the aforementioned global community of biomimicry & bio-inspired practitioners was conducted. A process of filtration based on individual services offered and their relevance to The Ray resulted in the narrowing of results to 16 highly feasible potential project pursuits. The spreadsheet for potential project pursuits can be accessed *here*. A graphical map of potential project pursuits can be accessed here. The spreadsheet for biomimicry practitioners and organizations can be accessed here. A graphical map of the practitioners and organizations can be accessed here.

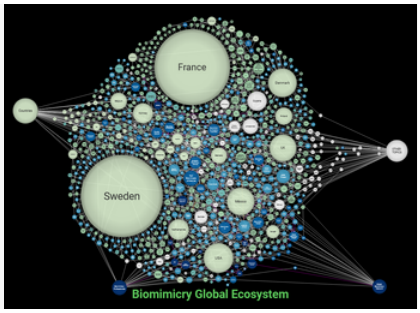
DETAILED DESCRIPTION

Existing bio-inspired services that have been identified as relevant to, and easily pursuable by The Ray have been identified. This information was acquired through market research, data collection via survey, and professional networking. Over 500 quality bio-inspired professionals received a request to complete the survey. 233 individuals responded to the survey, all of whom have opted into sharing their information with potential clients, as well as other bio-inspired practitioners. Approximately 70 consultants have been identified as bio-inspired providers of relevance to The Ray and approximately 16 potential project pursuits have been deemed relevant for the near future. Each individual's areas of expertise, alumni experience, offerings, organizational affiliation, and key words of relevance to The Ray have been documented.

Of all of these offerings, we have identified 15 as the most relevant potential projects to work with in the near future that are "low hanging fruits" for The Ray to pursue. These will be detailed out later in Section IV: Project Pursuits- Implementing Biomimicry in alignment with vision impact statement.

External links to various process documents:

- Outreach Material for Survey Request
- 500+ identified quality bio-inspired professionals
- Practitioner Survey
- Survey Results
- Surveyed People of Interest
- Near Future Project Pursuits Resulting from Market Research



C. EXISTING BIO-INSPIRED R1 RESEARCH INSTITUTIONS

(ALIGNS WITH GOAL II B. IDENTIFY EXISTING APPLIED BIOMIMICRY, BIO-INSPIRED PRACTITIONERS/SERVICES/OFFERINGS)

Collaborations with R1 Research Institutions directly align with The Ray's identity as Innovators and Capacity Builders as outlined in the Pillars section of the Fox Advancement report. There is an identified opportunity to create partnerships with R1 Institutions to develop research and training at the cutting edge of transportation and mobility. This multipurpose initiative creates a plethora of theoretical applications that can further be tested on the Ray while also providing key developments in the transportation industry that will establish The Ray as a national leader within the industry. Ideally the aim is to identify straightforward and low energy processes and projects that can organically generate funding through R1 research institutions with little input from staff.

DETAILS

The following section summarizes R1 Research Institutions identified in an initial market analysis that could potentially facilitate bio-inspired research on behalf of The Ray. The reflected institutions have been ranked by relevance criteria including (1). Participating in relevant research, (2). Established bio-inspired lab, (3). Seeking collaboration with The Ray, (4). Established Point of Contact via Survey, and (5). Locale.

These institutions were identified by market research initiatives, including the survey collection process mentioned above, in addition to a two week literature review conducted by College of Charleston's Research Librarian Geoff Timms, in which he identified over 120 primary literature articles referencing bio-inspired design relevant to The Ray, that can serve as a starting point for this endeavor. It is suggested to conduct additional literature review and mine these research topics and affiliated research institutions to continue building existing and potential tech collections.
The spreadsheet for R1 research institutions can be accessed *here*.
The graphical map for R1 research institutions can be accessed here.

" GARDENS ARE THE RESULT OF A COLLABORATION BETWEEN ART AND NATURE. "

- Penelope Hobhouse

SECTION III

SOLVING CHALLENGES ON THE RAY

ALIGNS WITH GOAL III: DEMONSTRATE DESIGN SOLUTIONS BY APPLYING BIOMIMICRY DESIGN METHODOLOGY TO THE RAY'S CHALLENGES AND GOALS

Demonstrate possible technology, process, system, or social innovation development by applying the biomimicry design thinking process to multiple challenges The Ray aims to solve, including but not limited to:
Zero Carbon, Zero Waste, Zero Deaths

A. BIOMIMICRY THINKING PROCESS ON THE RAY

(ALIGNS WITH GOAL III: DEMONSTRATE DESIGN SOLUTIONS BY APPLYING BIOMIMICRY DESIGN METHODOLOGY TO THE RAY'S CHALLENGES AND GOALS)

The Ray has a unique opportunity to guide biomimicry design thinking initiatives that solve for custom challenges within highway transportation systems.

APPLYING BIOMIMICRY

The biomimicry thinking process can follow two paths: (1) biology-to-design and (2) challenge-to-biology. The biology-to-design process begins with an inspiration from nature often via reconnection experience and results in the development of an innovative product, process, or system design. The challenge-to-biology process begins with the identification of a specific challenge and turns to nature for technical intel, biological intel, and inspiration to solve the identified challenge. For The Ray project, the challenge-to-biology process has been implemented to address specific challenges identified based on The Ray's goals.

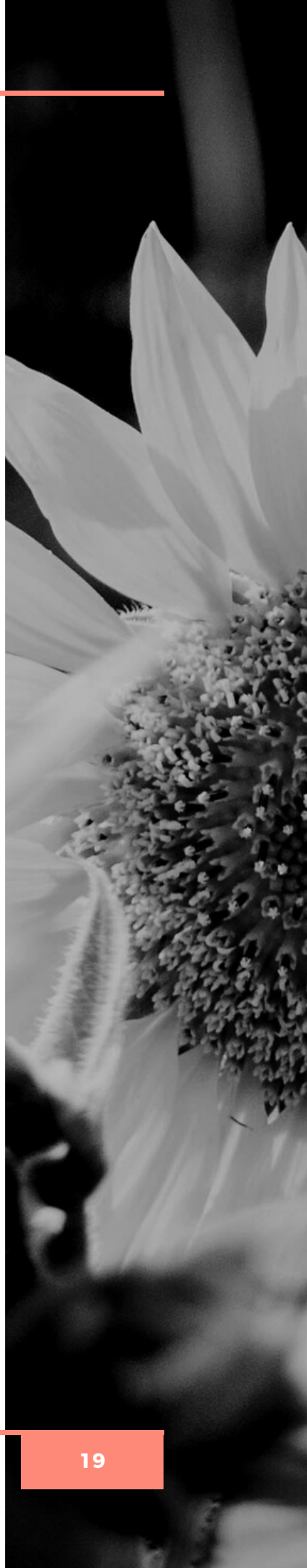
CHALLENGE TO BIOLOGY PROCESS

Mapping

To better understand The Ray's identified challenges, systems maps have been created through various lenses. An organic lens provides a map that starts at the center with the components and sub-components of The Ray Highway radially branching out accompanied by the corresponding processes. A structured lens provides a top down, goal oriented map. It begins with the three overarching goals of zero carbon, zero waste, and zero deaths and linearly flows through the system components and supply chain.

Challenge Identification and Functional Exploration

An initial focus on nine topics, eight of The Ray's 2020-2025 goals (reduce net carbon, improve road safety, improve traffic efficiency, reduce maintenance, reduce waste, reduce pollution, improve wellbeing, and reduce wildlife impact), plus social innovation guided the challenge identification effort. For each topic of focus, "How does nature do this?" was asked, and important context as it applies to The Ray Highway was identified.



Finalized Functions

Following the mapping of The Ray's identified challenges and the identification of functions related to each of the challenges, the functions were ranked against The Ray Highway's overarching goals of Zero Waste, Zero Carbon and Zero Deaths. One function from each category that best aligned with the top priorities within The Ray's sphere of influence was selected. These include:

1. Zero Carbon: How does Nature sequester carbon?
2. Zero Waste: How does Nature prevent water pollution and erosion?
3. Zero Deaths: How does Nature send and receive signals

DISCOVERING

The biomimicry thinking process can follow two paths: (1) biology-to-design and (2) challenge-to-biology. The biology-to-design process begins with an inspiration from nature often via a reconnection experience and results in the development of an innovative product, process, or system design. The challenge-to-biology process begins with the identification of a specific challenge and turns to nature for technical intel, biological intel, and inspiration to solve the identified challenge. For The Ray project, the challenge-to-biology process has been implemented to address specific challenges identified based on The Ray's goals.

CHALLENGE TO BIOLOGY PROCESS

Bio-Brainstorm

Once functions were selected a process called 'bio-brainstorming' was performed. A biological literature review was conducted to identify all biological models that accomplish the identified function. Through a multifaceted research approach, hundreds of potential organisms for each of the three functions were gathered. This list of organisms can be accessed here. For each function, this extensive organism list was narrowed to 10-15 organisms, following a narrowing process with selection criteria including availability of detailed research, and the organism's strategy's potential relevance to the highway ecosystem. The list is further narrowed to one organism per function. Three organisms selected include:

1. Common stony coral (Scleractinia) (zero carbon)
2. North American Beaver (Castor canadensis) (zero waste)
3. Big headed ant (Pheidole megacephala) (zero deaths)

CREATING

Strategy-Mechanism-Design Lesson

For each organism, a deep understanding of *the strategy*: **what an organism does to achieve that specific 'function'** and *the mechanism*: the details of **how** the organism goes about achieving that strategy was determined. These two aspects focus on the organism's biological elements related to form, process, or system. To make this scientific knowledge accessible to non-biological folks, a Design Lesson was created, which is a summary of the mechanism void of any biology. This design lesson serves as a bridge from biology to design and is the key nugget of information that can inspire The Ray Highway to create innovative and regenerative solutions to its challenges. While initial ideas around these design lessons have been brainstormed, future design charrettes that include interdisciplinary partners of The Ray could expand further on these ideas.

B. NATURE'S DESIGN LESSON (NDL) ZERO CARBON

COMMON STONY CORAL *(SCLERACTINIA)*

Relevance to The Ray: The Ray can affect community carbon emissions and waste-streams by incorporation of synthetically biomineralized materials into infrastructure construction projects and by exploring novel methods for synthetic biomineralization leveraging local chemical and material waste streams.

Strategy Description: Stony coral build reefs underwater using a biomineralization process using dissolved carbon dioxide and calcium ions to initiate calcium carbonate precipitation. Stony coral biomineralize calcium carbonate structures from dissolved carbon dioxide and calcium ions supported by enzymatic reactions and chemical regulation of pH to enable precipitation and nucleation in a super-saturated solution of dissolved calcium carbonate.

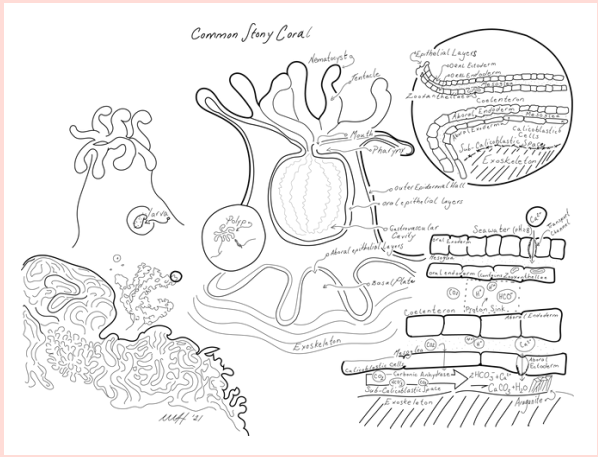


Image: Common stony coral bio-chemical process of biomineralization
(*Click image to open larger image in external window)*

Design Lesson:
Mineralization in a super-concentrated aqueous solution of calcium carbonate achieved by acid-based and metal ion-based catalysis between dissolved carbon dioxide and calcium-ions to initiate calcium carbonate precipitation onto an insoluble template. Control of pH in the reaction vessel by maintaining ratios of bicarbonate and carbonate ions to dissolved carbon dioxide. A pH of 8 to 8.25 will facilitate precipitation and can be maintained with relative concentrations around 90% bicarbonate, 10% carbonate, and <1% carbon dioxide.

Relative neutrality within the reaction vessel is facilitated by the export of hydrogen ions to an alkaline buffered proton sink and import of mineral (calcium) cations into the vessel at a ratio of two protons exported for each cation imported. Manual increase of weak acids and bicarbonate concentrations within the vessel can force sustained mineralization at nominal levels in lieu of a proton sink. Soluble additives, such as inorganic ions, weak acids, and organic polymers, influence polymorph selection, shape control, and hierarchical formations by stabilizing intercrystalline structures of less thermodynamically stable polymorphs. The lowest energy thresholds are achieved by precipitation of amorphous clusters. Post nucleation control of crystalline structures can be mediated by interactions with polymer additives as polymorphs stabilize over time.

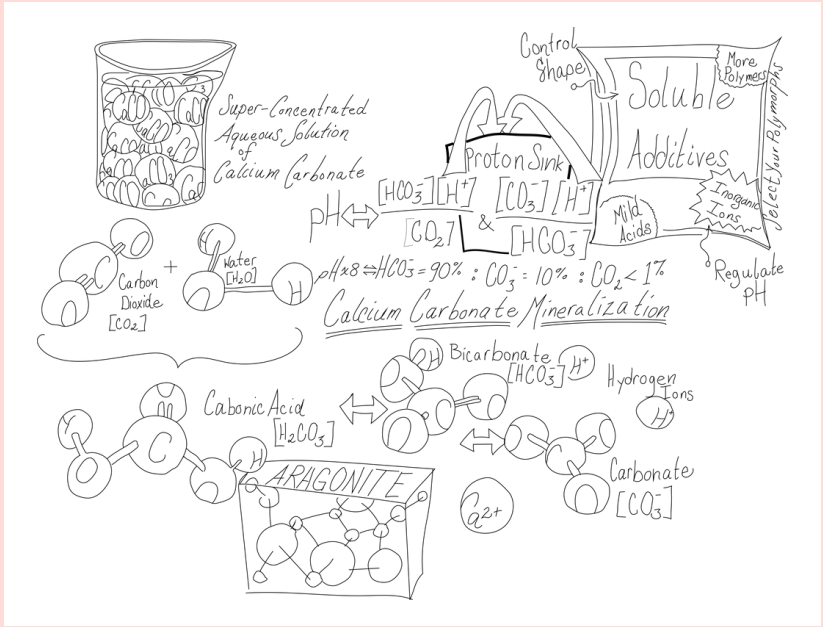


Image: Bio-chemical processes of sequestering calcium carbonate structures

(Click image to open larger image in external window)

Innovation Ideas (as applied to The Ray)

- Carbon as feedstock
- Sequestered industry carbon use to precipitate limestone materials
- Produce aggregate and clinker in cementitious mix designs
- Use in curing processes for carbon rich concretes
- Carbon recapture technologies (solvents, membranes, transport)
- Waste materials or chemicals could be used to scaffold process
- Link synthetic biomineralization to agriculture, forestry, tire residue

Note: This one pager is a summary of the comprehensive Nature's Design Lesson. Detailed NDL for Zero Carbon can be accessed here.

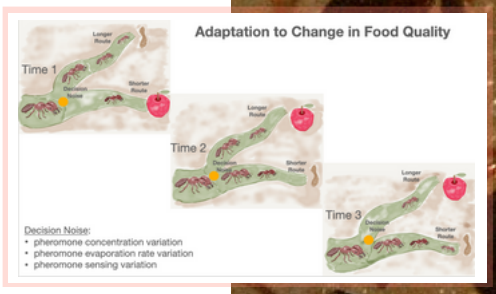
C. NATURE'S DESIGN LESSON (NDL) ZERO DEATHS

BIG-HEADED ANT *(PHEIDOLE MEGACEPHALA)*

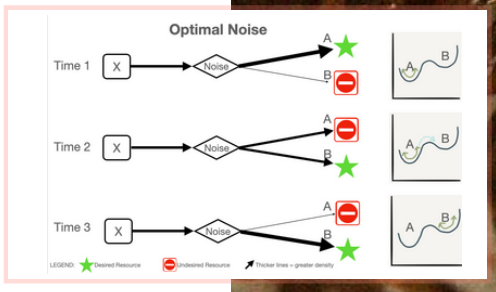
Relevance to The Ray: To improve traffic management, reduce deaths and improve efficiency, we looked at the 'functions' of self-organization, sensing, and response in nature.

Strategy Summary: The big-headed ant's optimized sensing error allows for quickly and efficiently maintaining access to the highest quality food even when the food source changes.

Strategy Description:
When the big headed ant must face two resources of different quality, the higher protein resource becomes the food of choice. If the quality of foods changes, the ants quickly adapt to the higher quality food. The information is self-organized via sensing and responding to pheromone trails. Error in the sensing and responding helps the big-headed ant adapt more quickly.



Mechanism
The self organization of the big headed ant is modeled by a mathematical function based on pheromone attributes. The optimal noise level calculated demonstrates the big-headed ant's balance between adaptability and efficiency.



Design Lesson
A self-organizing system can be mathematically modeled and optimized with a response to an offset periodic noise function.

Innovation Ideas (as applied to The Ray)

- CAV, platooning, navigation, and V2X algorithms
- Optimization of driver access to resources (battery charging, fuel, services, etc.)
- Organizational decision-making optimization

Note: This one pager is a summary of the comprehensive Nature's Design Lesson. Detailed NDL for Zero Carbon can be accessed here.

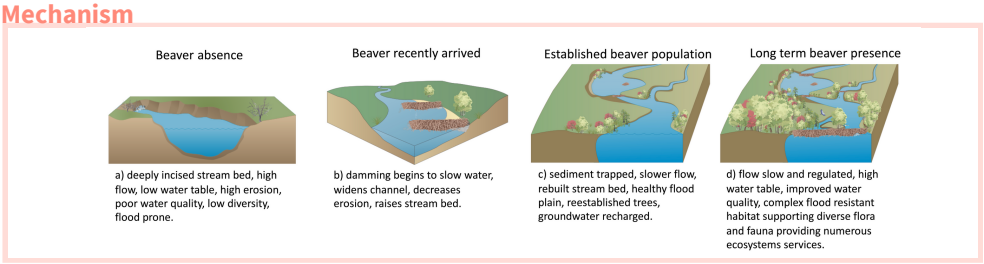
D. NATURE'S DESIGN LESSON (NDL) ZERO WASTE

NORTH AMERICAN BEAVER *(CASTOR CANADENSIS)*

Relevance to The Ray: Zero waste and zero death. Prevention of erosion, reduction of flood risk, filtration of particulates.

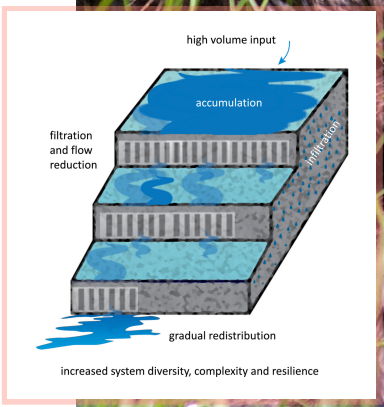
Strategy Description:
Beavers are engineers and farmers whose damming activity creates food and refuge for their families by cultivating diverse and cooperative wetland, forest, and meadow habitats.

Mechanism



Beaver dams are arranged in series. Upstream dams reduce the likelihood of downstream flooding. Permeability, at all flow levels, is key. The reduced kinetic energy of the dammed flow allows for capture, infiltration, cycling, and gradual redistribution of valuable resources, adding diversity and complexity. Increased resilience results. Regenerative capacity benefits the entire system.

Design Lesson
A stepwise series of impermanent, permeable obstructions lower kinetic energy, but do not completely block flow. Barricade permeability is key. Infiltration further slows downstream flow. Particulates are filtered, recaptured, temporarily stored, broken down and redistributed in a self-renewing process that adds complexity, diversity, and resilience to the system.



Innovation Ideas (as applied to The Ray)
Treat each interstate exit ROW as a separate watershed - Terraced, vegetated (native plants), permeable swales- Beaver dam analogue demos at partners outside GDOT regulation- Filter, recapture, upcycle tire wear particles from bridge runoff - Terraced green roofs, rain garden, permaculture, greywater reuse- Encourage traffic flow to stop and infiltrate the local economy- Slow the flow of ideas and people for organization resilience.

Note: This one pager is a summary of the comprehensive Nature's Design Lesson. Detailed NDL for Zero Carbon can be accessed here.

E. POTENTIAL CHALLENGE TO BIOLOGY PATHS

THE RAY HAS THE OPPORTUNITY TO GENERATE MULTIPLE CHALLENGE TO BIOLOGY DESIGN LESSONS RELEVANT TO THE TRANSPORTATION INDUSTRY

The Ray has identified multiple transportation related challenges which they aim to solve. The Ray can strategically identify paths forward to frame each of these challenges through the lens of “how would nature..." Biologizing the challenge, or converting the challenge into a function solved by the natural world, is an initial step towards identifying potential “challenge to biology” research paths. Areas of focus, including but not limited to agriculture, automation, ecosystem services, land management, materials, renewable energies, route optimization, safety, UAVs, V2X communication, etc. have been identified to organize potential “challenge to biology” paths. *Functions relevant to these areas* of focus have been identified, and are available for review and prioritization by The Ray. Identified paths of interest can be pursued both by paid professionals and by unpaid student research initiatives.

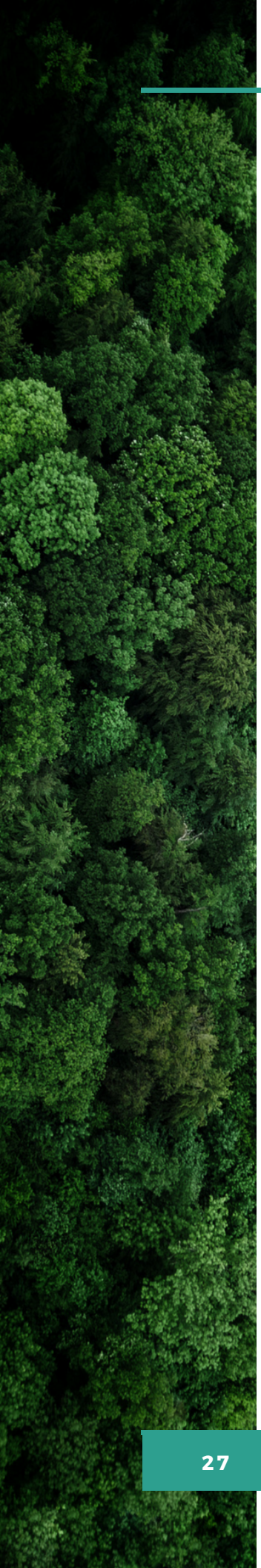
> “WHAT IF, EVERY TIME I STARTED TO INVENT SOMETHING, I ASKED, 'HOW WOULD NATURE SOLVE THIS?’”
>
> -Janine Benyus

SECTION IV

PROJECT PURSUITS: IMPLEMENTING BIOMIMICRY IN ALIGNMENT WITH VISION IMPACT STATEMENT

ALIGNS WITH GOAL IV. PROVIDE A COMPREHENSIVE BIOMIMICRY ANALYSIS FOR REGENERATIVE ADVANCEMENTS ON THE RAY.

Leverage life's principles analysis, genius of place reporting, bio brainstorm reports specific to The Ray's innovation challenges, measuring systemic outputs against Ecological Performance Standards, and apply the biomimicry design thinking methodology to currently existing technologies, processes, and systems on The Ray.



OVERVIEW

This research initiative has generated a host of viable and highly feasible biomimicry implementation opportunities for The Ray. The following section of the report is an overview of tools and potential project pursuits that can aid in The Ray's mission of restorative, regenerative highway transportation system innovation. Highlighted below are some of the readily available and easily accessible opportunities. A graphical map of these opportunities can be accessed here. A spreadsheet of the opportunities can be accessed *here*.

A.LIFE'S PRINCIPLES ANALYSIS (LPA)

"Life's Principles" are a set of overarching patterns common to all natural systems. These help set benchmarks against which we measure the efficacy of our sustainable strategies. We use Life's Principles as a measure for deeper sustainable practice in current land use, technologies, and design from the lens of economic and ESG factors. Life's Principles analysis (LPA) is a comprehensive auditing system that allows one to perform a comparative study of a design against the universal patterns of sustainability found throughout all living organisms currently thriving on earth.

LPA ON THE RAY

For The Ray Highway, Life's Principles can be used to audit all relevant initiatives, technologies, programs, and policies -including ecosystem restoration and conservation projects - that could impact the sustainable infrastructure design. This value-added service is scalable, based on science, and will help decrease GHG emissions and the risk of climate change-related damages through comparisons to the efficiency of biological systems. From a practical perspective, the audit will help determine gaps in current programs and practices of The Ray operations, along with opportunities for improvement.

When it comes to technologies, the LPA serves as an effective tool for identifying the sustainability of its processes and environmental impact. This assessment will help us to explain The Ray's resilience challenges, gaps in existing and developing technologies, programs, plans, and actions, and opportunities to design in harmony with nature. As a testbed, this also builds into The Ray, a framework for analysis and iterative improvement of all their initiatives with sustainability as the underlying foundation.

A demo of Asha Singhal's LP auditing tool can be accessed here. This has been developed for further customization depending on the needs of the project based on ESG metrics, LCA analysis, or SDG's.

Example of the Life's Principles Audit Tool used for a built environment audit: Arcade Providence.

POTENTIAL OPPORTUNITIES FOR THE RAY HIGHWAY LPA

a. Existing Technologies Audit:

- WheelRight
- Wattway
- Dot Technology
- Pollinator Garden
- 1 Megawatt Solar Field
- Solar Powered Vehicle Charging Unit
- Solar Tree
- Smart Planting Processes
- Bioswales
- Rubberized Roads
- V2X technologies
- Road striping
- Signage

b. Auditing Standard Designs Currently Implemented in Transportation and Mobility:

Auditing can be applied to standardized existing materials, technologies, processes and procedures utilized in infrastructure development in transportation and mobility. Auditable areas within transportation and mobility are vast and should be explored, identified and pursued.

c. Onset Auditing as a Tool to Guide New Pursuits:

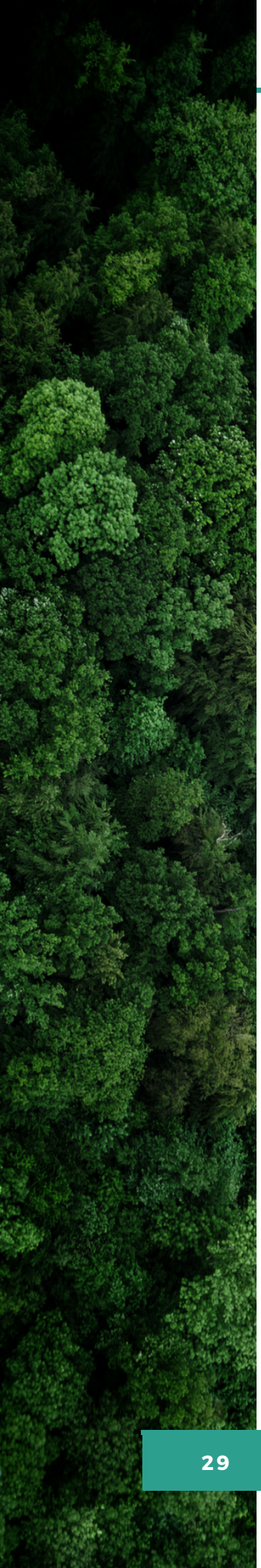
Life's Principles audits can serve as a guide when engaging in new pursuits, and can inform designs from the start in addition to serving as a regenerative revision tool. Leveraging this tool for a new pursuit gives The Ray the opportunity to provide life-friendly implementation suggestions to any future developments. Life's principles can guide any new innovation launches, programs, plans, projects, communications, collaborations, organizational developments, community engagement, social innovation, and more.

d. Auditing an Organization:

The auditing tool is versatile in that it supports the audit of entire processes and systems, including an organization's business model, their social structure and organizational efficiencies. The Ray has an opportunity to audit its internal organization and identify its strengths as a life-friendly initiative, as well as opportunities to increase the sustainability and health of the organization.

e. Auditing Community Engagement:

Auditing the efficiency, depth, and health of The Ray's community engagement on the local, state, regional, and federal levels can provide unique insight on new ways to approach varying levels of community engagement.



DEPTH OF AUDITS

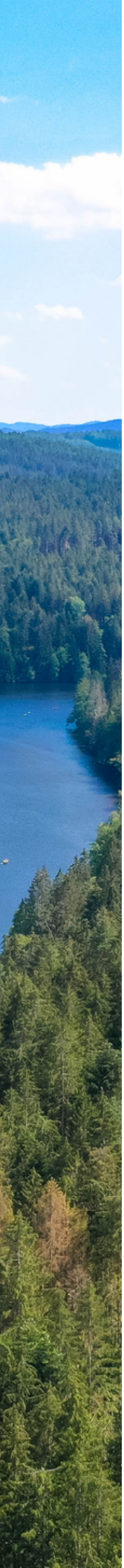
Life's principles audits can be taken to customizable depths based on the needs of the project and the client. Whether you're auditing an existing technology, a currently implemented standard design, a new project pursuit, the organization, or community engagement characteristics (local, state, regional or federal), each audit is customizable to varying levels of depth. We provide options for 3 levels of engagement:

- Extensive audit:
  - An extensive analysis of information regarding the entity being audited
  - Prioritize deep listening identifying needs of the project
  - Performing an extensive and iterative audit leveraging the LPA tool (ESG, SDG or LCA included)
  - Results are delivered as a combination of a detailed report along with the spreadsheet analysis
  - An extensive recommendations report is shared with customized levels of details through additional scoping of client needs

- Standard audit:
  - A detailed analysis of information regarding the entity being audited
  - Performing a thorough audit leveraging the auditing tool (ESG, SDG or LCA included)
  - Auditing results within the auditing tool spreadsheet
  - A summary report of the audit findings with standard suggestions of improvement

- Overview audit:
  - An analysis of relevant information regarding the entity being audited
  - Performing a thorough audit leveraging auditing tool
  - Results are delivered within the spreadsheet

> "After decades of faithful study, ecologists have begun to fathom hidden likenesses among many interwoven systems. ...a canon of nature's laws, strategies, and principles...Nature runs on sunlight. Nature uses only the energy it needs. Nature fits form to function. Nature recycles everything. Nature rewards cooperation. Nature banks on diversity. Nature demands local expertise. Nature curbs excesses from within. Nature taps the power of limits."
>
> - Janine Benyus



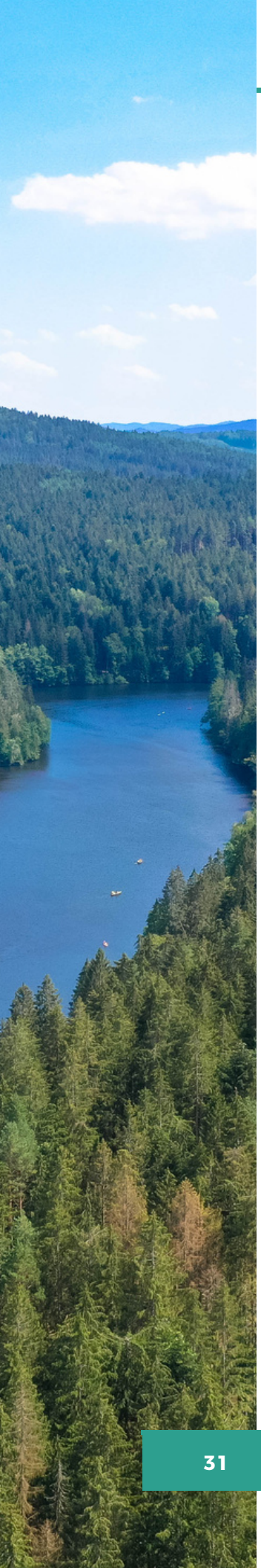
B. ECOLOGICAL PERFORMANCE STANDARDS

Ecological performance standards provide tangible, qualitative and quantitative paths forwards for infrastructure developments to function indistinguishably from the "wilderness next door." Using this approach leverages the hidden assets of the natural world, recognizing how ecological services provide many of the engineered functions that we typically design for (e.g. carbon sequestration, water retention and filtration, storm and energy dissipation, noise and air pollution reduction).

Ecological performance standards provide hard metrics to ensure specific human developments are generating the equivalent outputs as surrounding natural ecosystems. This will help The Ray in identifying how to meet or exceed these metrics to perform like a forest. Part of our team is trained in both mapping these hidden assets and learning how to creatively integrate them into a design through ecological engineering. The aim is to build long-term resilient strategies by understanding the trajectory of the socio-ecological system and building with this natural trajectory to significantly reduce energy consumption costs and increase the resilience of the development. This approach is multilevel biomimicry — consulting nature as a measure as well as model. The commitment to perform at the standard of local, thriving ecosystems is not simply an initiative to protect wildlife, it's a necessity for a development to deem itself regenerative.

Ecosystem Services are the services we get for free from the complex adaptive natural systems on earth. Committing to produce the same ecosystem services as the surrounding environment determines the infrastructure development goal of achieving regeneration. This initiative takes the vision beyond zero, into generous, life-positive design. Outlined below are some such ecosystem services:

- Moderate weather extremes and their impacts
- Temperature (degrees of cooling) (reduce urban heat island effect)
- Purify air (%pollutants captured)
- Purify water (%pollutants captured)
- Evapotranspiration (%rainfall returned)
- Phosphorus and nitrogen cycling (tons/acre)
- Carbon sequestration (tons/acre)
- Pollinate crops and natural vegetation
- Generate and preserve soil + renew their fertility (mm of soil created)
- Cycle and move nutrients
- Detoxify and decompose wastes
- Maintain biodiversity (%diversity of native species)
- Water collection + storage (Rainwater harvesting: gallons/storm)
- Mitigate droughts and floods - Stormwater management
- Disperse seeds
- Protect people from sun's harmful UV rays (%albedo)
- Protect stream and river channels and coastal shores from erosion
- Control pests numbers
- Contribute to climate stability
- Regulate disease carrying organisms
- Noise regulation
- Food production
- Health and wellbeing (Biophilia)
- Restorative amenities
- Microclimate conditioning



WHAT IS PROJECT POSITIVE?

“

Project Positive is a group of change agents dedicated to raising the bar on what acting sustainably means—driven by a sense of urgency to move beyond arbitrary reduction goals, to science-based targets and actions that are actually generous to the ecosystems, employees, and communities in which we operate.

The work of Project Positive builds on the vision of our co-founder, Janine Benyus —“when a city [or infrastructure development site] is functionally indistinguishable from the forest or wildlands next door, we’ve reached true sustainability”. To be “functionally indistinguishable” requires that we design and create spaces that perform as well as an existing local healthy ecosystem.

Biomimicry 3.8 launched Project Positive with a group of companies interested in applying the methodology to drive innovation, support climate goals, and engage employees. The group is working to demonstrate that manufacturers, campuses and schools, cities and urban developments can apply nature-based solutions and performance metrics to achieve positive impacts.

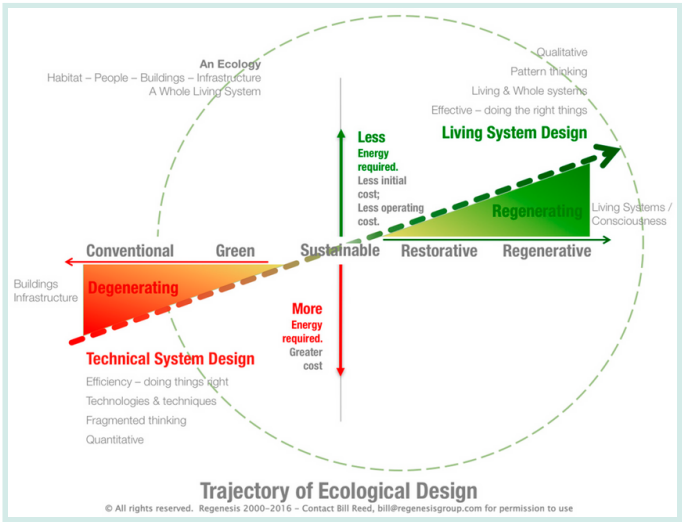
Together we are demonstrating what is possible, proving that nature-based design solutions optimize performance while benefiting people and the planet.

”

-Biomimicry 3.8

The pursuit of joining Project Positive, in collaboration with local community partners of impact, is arguably the highest ranking endeavor identified as project pursuits in terms of long-term impact.

Check out Interface’s pursuit here: Can a Carpet Factory function like a Forest?



C. GENIUS OF PLACE REPORT

The genius of place tool takes a deep dive into a particular eco-region's place-based natural contexts, constraints and opportunities to identify solutions exhibited by the locally attuned organisms evolved to thrive there. This endeavor researches details ranging from topography, annual precipitation patterns, and temperature regimes, to the diverse aspects of natural disturbances (variety, periodicity, and intensity). Additionally, this tool incorporates place-based traditional ecological knowledge. Two dozen champion-adapted species, frequently endemic, keystone species, or ecosystem engineers, are then deeply researched to identify their locally attuned strategies for thriving in place. The resulting design lessons are organized in a helpful taxonomy, illustrating overarching patterns. Emulating these well adapted place and context-specific natural strategies allows for more adaptable, resilient, efficient and regenerative designs that better fit into the landscape.

GENIUS OF PLACE ON THE RAY

The Ray is located within the southern outer piedmont ecoregion and the Chattahoochee river drainage system. Half of all Georgians drink water from this river. The soils along The Ray are described as "shrink-swell" because they swell under wet conditions in the winter and shrink during dry conditions in summer. A transitional area between the Appalachian foothills and mountainous ecoregions and the relatively flat coastal plain, The Ray's home territory is a complex mosaic of irregular plains and hills. Organisms that thrive within the pine, oak, and hickory woodlands along The Ray, such as the endemic southern red backed salamander or the champion adapted sweetgum tree, can offer expert advice for mitigating erosion, optimizing opportunities during the rainy season and overcoming the challenges of hardpan soils in the dry season. Savanna species, like the keystone gopher tortoise, an ecosystem engineer, offer strategies for building win-win cooperative relationships that optimize materials flow.
An example Genius of Place Report can be accessed here.

D. BIO-BRAINSTORM REPORT

PURPOSE SUMMARY OF BIO-BRAINSTORM REPORTS

Bio-brainstorm is a way of asking for nature's advice and then listening by quieting our human cleverness.

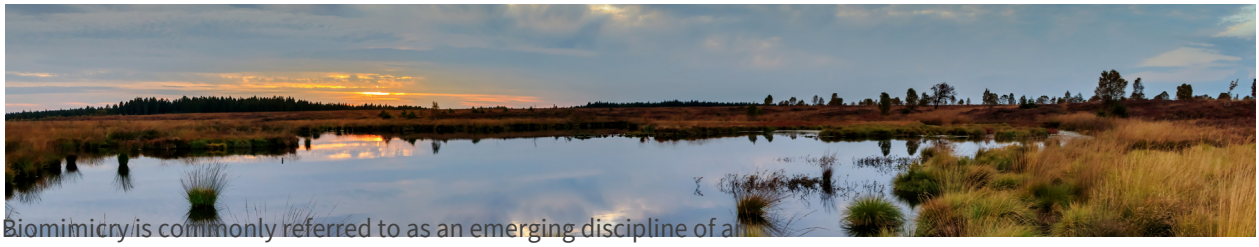
Challenges and goals are reframed as questions that are biologized. What does the design need to do? How would nature do this? For example, how would nature create color? How would nature filter water? How would nature redistribute resources locally? How would nature sequester carbon dioxide? How would nature distinguish between signals and background noise?

In a bio-brainstorm, at least 100 different natural mentors are consulted for each specific challenge or goal, yielding a broad and diverse set of potential strategies. Fifteen of the most promising problem solving strategies are targeted for research deep dives to thoroughly and accurately understand the biological function, strategy and mechanism in as much detail currently understood by science. Each detailed biological mechanism is then translated from biological terms into a concise design lesson written for the target audience, such as engineers, urban planners, strategists, designers, architects or manufacturers to work with. These design lessons are designed to stay true to the biological mechanism and its underlying scientific principles. They inform and springboard numerous well adapted, creative, novel, innovative ideas for the regenerative solutions we seek.

Example Bio-Brainstorms for Zero Carbon, Zero Waste and Zero Deaths challenges for the Ray that were conducted in 2021 can be found *here* as detailed spreadsheets. These spreadsheets typically form a part of the deliverable focusing on research, which is then followed by a summary report available upon request.

E. TRADITIONAL ECOLOGICAL KNOWLEDGE AND BIOMIMICRY

"A RECENT STUDY FROM THE NATIONAL ACADEMY OF SCIENCE FOUND THAT NATURE-BASED SOLUTIONS CAN PROVIDE MORE THAN "ONE-THIRD OF THE COST-EFFECTIVE CLIMATE MITIGATION NEEDED BETWEEN NOW AND 2030 TO STABILIZE WARMING TO BELOW 2 DEGREES CELSIUS."



Biomimicry is commonly referred to as an emerging discipline of an ancient practice. Research, informed by euro-centric, scientific biological knowledge, plays a valuable role in informing successful biomimetic design. Knowing however, is different. Knowing is informed by a connected relationship with the natural world. When exploring the field of biomimicry, it is important to recognize its role as a bridge to bring together both technical scientific knowledge, and the importance of being attuned to the natural world. The historical degradation of land, disillusionment that humans are not nature, anthropocentrism that centers humans as separate from and superior to non-human species, and the extractive, exploitative mentality of our culture has bred a societal disconnect from our greatest source of knowledge. We have the opportunity to respectfully recognize that indigenous peoples are deeply connected to and informed by the natural world, and have been drastically harmed by colonial culture, and this has to take place while simultaneously pulling technical, effective biological knowledge to the forefront of our regenerative missions. We honor The Mvskoke (Muscogee/Creek) people, on whose traditional land The Ray resides and encourage further acknowledgement and respect for the tradtional ecological knowledge held by indigenous peoples globally.

"VIRTUALLY ALL NATIVE CULTURES THAT HAVE SURVIVED WITHOUT FOULING THEIR NESTS HAVE ACKNOWLEDGED THAT NATURE KNOWS BEST, AND HAVE HAD THE HUMILITY TO ASK THE BEARS AND WOLVES AND RAVENS AND REDWOODS FOR GUIDANCE."

- Janine Benyus

F. BIOMIMICRY FOR SOCIAL INNOVATION

(ALIGNS WITH GOAL V. LEVERAGE BIOMIMICRY METHODOLOGIES TO IMPROVE SOCIAL INNOVATION INITIATIVES AT THE RAY)

Biomimicry applied to social innovation is the act of looking to the natural world to guide the way we engage human social systems. Evaluating nature's deep patterns with the intention to inform social systems leads to social breakthroughs that create life-friendly conditions. What if our society, organizations, and leadership practices functioned like nature; balanced, locally attuned, efficient, collaboratively, within tightly closed loops? When looking to nature to inform social innovation decision making, it is key to leverage deep natural patterns that show up consistently, rather than emulating individual organisms to inform these decisions. Life creates conditions conducive to life, and so should our human systems.

BIOMIMICRY FOR SOCIAL INNOVATION PURSUITS RELEVANT TO THE RAY

a. Organizational Development Inspired by Nature

- Individual Staff and Leadership Capacity
  - Individual Resilience Training and Locally Attuned Deck
  - Living Systems Leadership Training and Coaching
  - Life's Principles Leadership Training and Card Deck
- Organizational Health and Resilience
  - Organizational Health Indicator Assessment
  - Mapping the Organization as a Healthy, Thriving Ecosystem
  - Adaptive Cycle Training
- Evolutionary Strategic Development
  - Life's Principles Organizational Audit
  - Nature Inspired Organizational Strategic Planning (1, 3, 5 years planning periods)
  - Powerful Partnerships: Mutualisms, Cooperation & Symbiosis Training
  - Other customized organizational training
  - Immature vs Mature Ecosystem Characteristics Mapping

b. Local Community Engagement

Community engagement informed by nature is locally attuned and responsive, creates feedback loops with community constituents, leverages readily available materials and energy, and creates multifunctional opportunities to engage various communities.

Opportunities for Multi-functional Human-Nature Reconnections Along The Ray

Multi-functional Human Nature Reconnection: Providing the community with something that is of value to them, would help them care about The Ray's initiatives as a mutualistic exchange. For example, creating a nature reconnection stopping point along The Ray, by providing a safe place to enjoy the flowers/pollinators. Weekend visiting opportunities that appeal to local demographics (sunflower fields, nature path, eco-future of transportation).

c. State, Regional, and Federal levels of Community Engagement

- State: Social Innovation LPA on The Ray's State Community Engagement
- Regional: Social Innovation LPA on The Ray's Regional Community Engagement
- Federal: Social Innovation LPA on The Ray's Federal Community Engagement

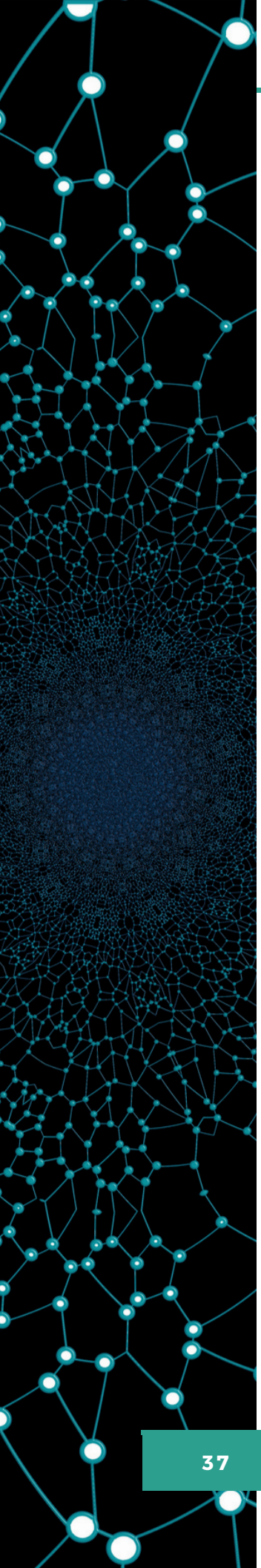
d. Equitable Transportation Opportunities Inspired by Nature

- Leverage deep patterns in nature to inform equitability impacts of systemic implementations
- Systematic mapping of equity, inclusion and diversity

e. Biomimicry in Law and Policy

A comprehensive explanation of each bulleted path forward will be provided prior to report summary review.

- Inlaying BMY design thinking process with policy design process
- Evaluating existing policy through LP / Deep pattern lensing
- Leveraging Deep pattern analysis for creation of new policy to support environmental and systems integration
- Systems thinking mapping and Policy Cascades analysis



G. BIOMIMICRY ON THE RAY EXTERNAL COMMUNICATIONS

(ALIGNS WITH GOAL VI. EXTERNAL STAKEHOLDER BIOMIMICRY COMMUNICATION)

Biomimicry on The Ray's 2021 goal was to develop a strategic biomimicry communications plan beginning in the final quarter of 2021 and beyond. The developed plan serves multifaceted roles of introducing and socializing biomimicry to The Ray's direct audience, and establishing The Ray as a cutting edge innovator taking note of bio-inspired design within the bio-inspired design community.

COMMUNICATING THE RAY'S INNOVATION MARKET POSITION TO BIO-INSPIRED COMMUNITIES

Biomimicry on The Ray engaged in communicating and establishing feedback loops with the bio-inspired community to position The Ray as a regenerative entity interested in leveraging biomimicry in the future. This communication initiative included connecting with over 500 bio-inspired designers, and responsive engagement with over 200 bio-inspired designers. The communication initiative has resulted in a multitude of findings relevant to The Ray, as presented in the research report summary. The Ray has an opportunity to continue engagement with this community to position itself as an innovator interested in the bio-inspired market.

COMMUNICATING BIOMIMICRY TO THE RAY'S TRANSPORTATION AND MOBILITY AUDIENCE

Biomimicry on The Ray engaged in a communication initiative that includes twice a month delivery of educational excerpts to The Ray's social media audience, to engage in the early stages of socializing the concept of biomimicry to the transportation and mobility audience. The Ray is framing itself as an innovation initiative that is pursuing cutting edge regenerative research and future design. Interest in bio-inspired design among The Ray's transportation and mobility audience contributes to The Ray's market position as a cutting edge innovator in the regenerative design space.

SECTION V

THE FUTURE OF BIOMIMICRY ON THE RAY

ALIGNS WITH GOAL VII. IDENTIFY THE FEASIBILITY OF IMPLEMENTING EACH SUGGESTED BIOMIMICRY PURSUITS

Provide feasibility information regarding any suggestions put forth in the biomimicry implementation pursuits document including but not limited to time requirements, budget estimates, resource allocation, and potential legal restrictions.

A. Feasibility Studies

(ALIGNS WITH GOAL VII. IDENTIFY THE FEASIBILITY OF IMPLEMENTING EACH SUGGESTED BIOMIMICRY PURSUITS)

A LITTLE BIT ABOUT THE FEASIBILITY OF IMPLEMENTATION

FEASIBILITY STUDY OF SUGGESTED PROJECT PURSUITS

A feasibility study for the suggested project pursuits is included in the suggested project pursuits graphic. Criteria identified for feasibility are time investment required, cost investment required and obvious legal restrictions presented by the individual pursuit.

FEASIBILITY STUDY OF EXISTING BIO-INSPIRED TECHNOLOGIES

A preliminary feasibility study within the scope of this project pertaining to existing bio-inspired technologies has been conducted. An initial market research initiative was launched to identify current market readiness, price points and obvious legal restrictions for implementation pursuits of existing technology. Existing bio-inspired technologies will require additional, official feasibility reporting conducted by a qualified feasibility study provider that should be conducted following the identification of technologies The Ray is interested in pursuing based on the preliminary feasibility study completed within this report.

B.NEXT STEPS... 2022 AND BEYOND

THE NATURE OF THIS REPORT

This research summary report is intended to serve as the tip of the iceberg of the potential of leveraging bio-inspired design in amplifying regenerative design efforts of The Ray. The path forward can be as research oriented, custom paced, and carefully curated as The Ray stakeholders see fit. The information gathered and the delivery format of this report is intended to guide The Ray in building from the bottom up in their efforts to implement biomimicry. The report can be leveraged to inform and develop a customized plan forward for The Ray.

WHAT'S TO COME...

Confirmed Dates

- **January 28, 2022** (3:00pm-4:00pm ET)--- Collectively review Biomimicry on The Ray research report
- **February 4, 2022** --- Launch weekly 15 week training sessions
- **May 26th 2022** (4:00pm-5:30pm ET) --- Complete 15 week Friday training sessions

PATH FORWARD...

Suggested Dates

- **January 2022 -**-- Engage in student led research through existing Bio-Brainstorm and Biomimicry Design courses at university level, to scope out more of The Ray's challenges
- **May 2022 -**-- Attend Biocene 2022, NASA's Glenn Research Bio-Inspired Conference, Transportation Themed (as an attendee role or a speaker)
- **July 1st - Dec 2022** --- Engage with assimilation sessions with the Biomimicry at the Ray team (details below)
- **Early 2023** --- Engage with potential project pursuits of interest (as outlined in Section IV)
- **Early 2023 ---** Tour Georgia Technical Institute's Center for Biologically Inspired Design

ASSIMILATION SESSIONS

Assimilation Sessions of identified components of the research summary report are highly encouraged and outlined below. While all of the research materials identified for The Ray have been summarized in this report, there are nuances in each area that could be further expounded upon as The Ray sees fit. The intention of assimilation sessions is for each of the identified sections to be revisited following the implementation of the 15 week training. Each section will be elaborated with the option to pursue deeper dives. Assimilation sessions are intended to break the comprehensive materials of this report down into digestible segments.

Suggested Assimilation Sessions

- Existing Bio-Inspired Technologies
- Project Pursuits stemming from existing consultants/services/offerings
- Existing R1 Research Institutions and developing a standardized collaboration model
- Life's Principles Audits
- Challenge to Biology Research Collections
- Genius of Place Reporting
- Ecological Performance Standards
- Biomimicry for Social Innovation Opportunities
- Any additional topics as requested by The Ray

BIOMIMICRY ON THE RAY FUTURE PROJECT PURSUITS & OPPORTUNITIES

Establish The Ray as a Research Leader in Bio-Inspired Transportation and Mobility

- The Ray is uniquely positioned to establish itself as holding the most comprehensive set of publicly collected data of bio-inspired design relevant to transportation and mobility, and the opportunity to conduct ongoing research to grow this data set.
- To date, The Ray is the only entity that has identified and surveyed the multidisciplinary collection of bio-inspired communities in this manner. The general response from those surveyed was genuine excitement regarding the robust platform of wide ranging areas of relevant application spaces.
- Providing a platform to display current research initiatives relevant to transportation and mobility and highlighting The Ray's interest in bio-inspired pursuits, will position The Ray as forward thinkers in the regenerative design space within both the bio-inspired community and the transportation industry.
- A phase 2 build out of relevant practitioners and ongoing research initiatives is a viable pursuit.

Explore Implementation of Identified Existing Technologies

- The Ray can explore existing technologies and pursue next steps for implementation of various relevant technologies, by leveraging the existing technologies map, market readiness levels, price points, established contacts and relevance cases for each identified tech.

- A phase 2 build out of the existing technologies map is a viable and valuable pursuit. There is potential for this to be an ongoing, formalized effort that tracks the current technology market and positions The Ray to be leaders in current bio-inspired technologies relevant to transportation and mobility.

SERVE AS A SYSTEMS REPRESENTATIVE FOR BIO-INSPIRED PURSUITS IN TRANSPORTATION AND MOBILITY

While many bio-inspired individuals and entities are specializing in single aspects of transportation and mobility, no one is serving as a hub of connection for all of these entities. Currently, no identified entity is taking a systems level approach of linking these individualized efforts together in a single space. The Ray has an opportunity to serve as a bridge between researchers, innovators, and future implementers.

LEVERAGE BIOMIMETIC TOOLS TO GENERATE NEW INNOVATION PATHS

- All suggested tools have been deemed highly feasible, with low costs, minimal staff investments, and low to no legal restrictions.
- Tools have been identified and explained within the summary report and will be further elaborated in the 15 week training sessions. Assimilation sessions or deep dives into the identified biomimicry tools following the 15 week training are suggested for late 2022.
- Generate a Genius of Place Report to inform The Ray and better understand the broader socio-ecological context of The Ray highway.
- Generate Bio-Brainstorm Reports guided by set regulatory restrictions relevant to The Ray to address identified challenges along the highway and highlight innovation opportunities for future pursuits.
- Run Life's Principles Audits in areas deemed most relevant by The Ray
- Pursue Ecological Performance Standard Metric Generation and develop a plan to achieve determined standards. Join Biomimicry 3.8's Project Positive.

FACILITATE LOW INVESTMENT RESEARCH WITH UNDERGRADUATE AND GRADUATE LEVEL STUDENTS

- To continue building The Ray's research collection of bio-inspired transportation innovation, certain project pursuits are highlighted that require zero dollars and minimal time investment. As a low energy process, it leverages readily available materials at no expense to The Ray.
- The Ray has the opportunity to formalize their role in serving as undergraduate and graduate research "clients" that guide students to solve identified challenges along The Ray. This multifunctional initiative engages students to think about and push the frontiers of bio-inspired design in transportation and mobility while solving challenges relevant to The Ray. In addition, it establishes The Ray as a forward-thinking regenerative design agency without extensive resource allocation towards the initiative.

GUIDE R1 RESEARCH INSTITUTIONS TO LOOK AT THE RAY'S IDENTIFIED RESEARCH PATHS IN TRANSPORTATION AND MOBILITY

- Leveraging relationships with Georgia Tech's Center for Biologically Inspired Design, The Ray can develop a replicable model of R1 Research Institution Engagement with investment constraints in place that require fundraising on the R1 Research Institutions' behalf.
- Developing a systems map of identified challenges for potential bio-inspired research solutions that can be provided to various bio-inspired design labs and a collaboration model that requires minimal investment from The Ray can amplify bio-inspired research initiatives focusing on transportation and mobility.

COMMUNICATE WITHIN BIO-INSPIRED NETWORKS TO ESTABLISH THE RAY AS A REGENERATIVE DESIGN INITIATIVE WITH BIO-INSPIRED INTERESTS

While The Ray is engaging in early stages of bio-inspired design pursuits, it is advantageous to establish and continue communication within the bio-inspired design community to guide research focus of groups seeking research topics. The Ray can invest minimal resources into continuing communication initiatives within this community to establish themselves as the first regenerative transportation and mobility initiative to engage in this capacity.

CONTINUE EARLY STAGE, RESEARCH ORIENTED EXPLORATIONS OF BIOMIMICRY

This comprehensive report reflects current and relevant project pursuits. The nature of this report is a snapshot of a dynamic field with continually developing opportunities. The Ray is uniquely positioned to continue exploring biomimicry as a programmatic lens, and identify ways in which biomimicry can lead to more regeneration on The Ray.

SECTION VI

ADDITIONAL DOCUMENTS

TEAM BIOS, EXTERNAL CONTRIBUTORS, A GLOSSARY, REFERENCES CITED, APPENDICES, AND ACKNOWLEDGEMENTS ARE INCLUDED IN THE FOLLOWING SECTION

All documents supporting this research are linked in this section for your reference.

A.BIOMIMICRY ON THE RAY TEAM

THE INTERDISCIPLINARY TEAM BEHIND THIS PROJECT

ASHA SINGHAL

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COMMUNICATIONS MANAGER,
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Asha is a biomimic, architect, researcher, urban planner, and educator specializing in natural philosophy. Her vision with her work is to create pragmatic narratives of hope by emulating natural principles, to bridge the gap between the built and natural environments. Her focus is on creating a future that is resilient and just for all.

MCCALL LANGFORD

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McCall dedicates her career to environmental stewardship, and ecological advocacy through human design improvement. McCall has a background in business, non-profit development, and climate related grant-making. McCall holds biomimicry design thinking at the center of her regenerative design career.

DEB BIDWELL

BIOLOGY RESEARCH
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Deb is a biomimic, biologist, educator, naturalist, optimist, leader and explorer who has been passionately sharing biology and sustainability related innovation for more than twenty-five years. Deb's goal is to promote deep reconnection, awe, inspiration, and action through her regenerative work.

RICH ALTHERR

RESEARCH FACILITATOR,
SYSTEMS MAPPING

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Rich galvanizes automotive engineers to incorporate Nature's technical knowledge into future sustainable engineering designs. These innovative methods bring new insight into vehicle components, systems, and processes benefiting a company's carbon-neutral goals and participation in the emerging circular economy.

Our team comprises interdisciplinary professionals with a collective expertise in holistic sustainable design using biomimicry, biophilia, and nature based design. With experience in award winning international projects, we bring our deep understanding of emulating living systems to ensure long term sustainability and a project that works in harmony with nature.
All Team Bios can be accessed *here*.

A.TEAM

EXTERNAL CONTRIBUTORS

GEOFF TIMMS
is a Research Librarian at the College of Charleston Marine Resources Library who kindly assisted with primary literature review for our bio-inspired and biomimetic technologies research.

NICHOLAS HEIER
Biomimicry and Operations Design and Management graduate student at Arizona State University. Nick kindly assisted our NDL for Zero Carbon by researching carbon sequestration in Scleractinian coral as part of his fall 2021 internship with Sharing Nature's Genius, LLC.

MICHELLE FEHLER
Clinical Assistant Professor at Arizona State University & Biomimicry Professional at Biomimicry 3.8. Our team collaborated with Michelle and her fall 2021 Biomimicry and Design students. Her students engaged in a biology to design module inspired by mentors generated by our team's bio brainstorm.

CATALINA BUSTILLO & **FLAVIA BISI**
Certified Biomimicry Professional fellows who assisted our team with Nature's Design Lesson template creation in conjunction with their roles at Sharing Nature's Genius, LLC.

B. GLOSSARY

Word	Definition	Word	Definition
Abstracted Design Principle	A design principle implimented by an organism that has been translated for designers to leverage. A design principles originating biologically that has been translated to intended design audiences.	Genius of Place Report	A research report evaluating a "reference site" or a biologically thriving and in-tact site that is a local representative for a specific site. The report identifies local operating conditions to which an infrastructure build is suseptible, identified organisms that display emulatable adaptations that generate abstracted design principles that can influence locally attuned design.
Bio-Brainstorm	The act of researching and identifying organisms that solve for the identified functional challenge of which a design is aiming to solve	isite	A nature reconnection activity that prompts a biomimetic lensing
Bio-Inspired Design	The application of knowledge of biological systems in research and development to solve technical problems and develop technical inventions and innovations	Keystone Species	A species on which other species in an ecosystem largely depend, such that if it were removed the ecosystem would change drastically.
Biodiversity *	The variety of life and its processes; it includes the variety of living organisms, the genetic differences among them, and the communities and ecosystems in which they occur	Life's Principles *	A set of patterns exhibited by life that contributes to life's ability to survive and thrive.
Biology to Design *	The biomimicry approach to design that starts with discovering natural models and goes through the steps of abstracting design principles, brainstorming potential applications, emulating nature's strategies, and evaluating the design against Life's Principles	Life's Principles Audit	An audit in which a design is evaluated against a set of patterns exhibited by life that contributes to life's ability to survive and thrive.
Biomimetic	A design that is inspired by nature's genius that incorporates emulation, ethos and reconnect components	Literal Emulation	Emulating nature in physical and tangible designs
Biomimicry	The concious emulation of nature's genius	Mechanism	The details of how the organism goes about achieving that strategy was determined
Biomimicry Design Thinking Process	The process of scoping a client's design needs, identifying the functional challenge the client faces, discovering natural models solving for the identified challenge, creating a biomimetic design solution that addresses the challenge, and evaluating the design against Life's Principles.	Methodology	A system of methods used in a particular area of study or activity
Challenge *	A specific issue or need that an organism faces, and a specific issue	Nature Based	The 'Nature-based design' principle means that natural processes
Challenge to Biology	Biomimicry process that includes identifiying a design challenge followed by identifying organisms performing functional solutions relevant to the identified challenge	Nature Design Lesson (NDL)	A Nature's Design Lesson (NDL) is report curated by Sharing Nature's Genius that translates well adapted biological lessons into the language of designers and engineers to promote regenerative design.
Conceptual Emulation	Emulating nature to create intangible designs like organizational processes and processures, laws, decision making processes, etc.	Nature Positive Design	Designs that have a net-positive impact on the surrounding natural environment (carbon sequestration, water filtration, social impact, etc)
Creating Phase	The phase of the biomimicry design process that includes abstracting a design principle and creating a human design inspired by nature	Operating Conditions *	Several known factors that influence the way life -- biological organisms and systems -- persists on Earth. These operating conditions help us to explain the context that life must exist within to survive and thrive on our planet
Discovering Phase	The phase of the biomimicry design process that includes identifying organisms that are solving a relevant functional challenge	Process Emulation	Emulating processes that organisms carry out in nature
Ecological Performance Standards	Setting design standards that match that of the outputs of the surrounding ecosystem, ensuring regenerative characteristics of human designs	R1 Research Institution	"Research I university" is a category that the Carnegie Classification of Institutions of Higher Education uses to indicate universities in the United States that engage in the highest levels of research activity.
Ecosystem Engineers	Species that modify their environment in a significant manner, creating new habitats or modifying existing ones to suit their needs.	Reconnect	The act of intentionally engaging in a multifacted relationship with the natural world.
Ecosystem Services	Ecosystem services are the many and varied benefits to humans provided by the natural environment and from healthy ecosystems	Regenerate/ Regeneration/ Regenerative *	Restore to a better, higher, or more worthy state than the existing one/tending to or characterized by the action of that which renewably or sustainably reproduces or reforms.
Emulation *	The mimicing of deep patterns or principles rather than directly copying them.	Restorative	Having the ability to restore health, strength, or a feeling of well-being."the restorative power of long walks"
Endemic	(Of a plant or animal) native and restricted to a certain place. "a marsupial endemic to northeastern Australia"	Scoping Phase	The phase of the biomimicry design process that involves closely connecting with and understanding the design challenge at hand. The scoping phase includes data collection, review and interpretation, stakeholder interviews, and collaboration between biomimics and clients
Ethos	The characteristic spirit of a culture, era, or community as manifested in its beliefs and aspirations. "a challenge to the ethos of the 1960s"	Social Innovation	The design and implementation of new solutions that imply conceptual, process, product, or organisational change, which ultimately aim to improve the welfare and wellbeing of individuals and communities.
Evaluating Phase	The phase of The phase of the biomimicry design process that includes comparing the generated design to Life's Principles to identify if there are areas of further life-friendly improvements	Strategy	What an organism does to achieve that specific 'function'
Form Emulation	(or structural emulation) Emulating natural physical form displays in nature (eg - surface structures, shapes, dimensional distributions etc.)	Symbiotic	Involving interaction between two different organisms living in close physical association. "the fungi form symbiotic associations with the roots of plant species"
Function *	The action of which a biological strategy is specifically fitted or used, or for which a thing exists; purpose or need. The mode of action by which something fulfills its purpose.	System Emulation	Emulating multiple organisms that operate within a cohesive ecological system to generate system characteristic present within a living ecosystem
		Traditional Ecological Knowledge	Traditional Ecological Knowledge, also called by other names including Indigenous Knowledge or Native Science, (hereafter, TEK) refers to the evolving knowledge acquired by indigenous and local peoples over hundreds or thousands of years through direct contact with the environment.

(Click on the image above to visit the external link with the full glossary.)

C.REFERENCES

Baumeister D, Tocke R, Dwyer J, Ritter S, Benyus JM. Biomimicry Resource Handbook: A seed bank of best practices. Missoula, MT: Biomimicry 3.8; 2014. https://biomimicry.net/the-buzz/resources/biomimicry-resource-handbook/

Big-Headed Ant, Pheidole Sp." 2013. Tamu.Edu. December 4, 2013. https://urbanentomology.tamu.edu/urban-pests/ants/big_headed/.

Dey, A., de With, G., & Sommerdijk, N. A. J. M. (2010). In situ techniques in biomimetic mineralization studies of calcium carbonate. Chem. Soc. Rev., 39(2), 397–409

Dussutour, A., M. Beekman, S. C. Nicolis, and B. Meyer. 2009. "Noise Improves Collective Decision-Making by Ants in Dynamic Environments." Proceedings. Biological Sciences 276 (1677): 4353–61.

Gattuso, J.-P., Allemand, D., & Frankignoulle, M. (1999). Photosynthesis and Calcification at Cellular, Organismal and Community Levels in Coral Reefs: A Review on Interactions and Control by Carbonate Chemistry. American Zoology, 39(1), 160–183..

Goldfarb B. 2019. Eager: The surprising, secret life of beavers and why they matter. White River Junction, VT: Chelsea Green Publishing.

Hawken P. Regeneration: Ending the climate crisis in one generation. Penguin Books; 2021. https://paulhawken.com/

Meyer, Bernd. 2017. "Optimal Information Transfer and Stochastic Resonance in Collective Decision Making." Swarm Intelligence 11 (2): 131–54.

Pollock et al 2014. Using beaver dams to restore incised stream ecosystems. Bioscience, 64(4), pp.279-290.

Project positive. Biomimicry 3.8. 2021 Mar 6 [accessed 2021 Nov 21]. https://biomimicry.net/project-positive/

Puttock et al 2017. Eurasian beaver activity increases water storage, attenuates flow and mitigates diffuse pollution from intensively-managed grasslands. Sci Total Environ. 576:430–443.

Resnick B, Zarracina J. All life on Earth, in one staggering chart. Vox. 2018 May 29 [accessed 2021 Nov 21]. https://www.vox.com/science-and-health/2018/5/29/17386112/all-life-on-earth-chart-weight-plants-animals-pnas

Thompson et al 2021. Ecosystem services provided by beavers Castor spp. Mamm Rev. 51(1):25–39.
Wright JP, Jones CG, Flecker AS. 2002. An ecosystem engineer, the beaver, increases species richness at the landscape scale. Oecologia. 132(1):96–101.

Yeang K. Saving the planet by design: Reinventing our world through ecomimesis. London: Routledge; 2020. https://www.routledge.com/Saving-The-Planet-By-Design-Reinventing-Our-World-Through-Ecomimesis/Yeang/p/book/9780415685818

Yazici, O., & Karaman, F. (2019). Biomimetic crystallization of calcium carbonate in the presence of water-soluble zwitterionic block copolymer. Polymer Engineering & Science, 59(1), 96–102.

D.APPENDICES

ALL DOCUMENTS SUPPORTING THIS RESEARCH ARE LINKED IN THIS SECTION FOR YOUR REFERENCE.

APPENDIX- SECTION I

I.B.1: What surrounds us (Scientist Weigh all of Life)
I.C.1: Detailed Scoping Process Visual Graphic (*)
I.C.2: Technologies for The Ray 2015-2020 (*)
I.C.3: Building The Ray's Roadmap for 2020-2025 (*)
I.C.4: Featured articles and publications
I.C.5: Scope of Work
I.D.1: Biomimicry Literacy Goals (*)
I.D.2: Biomimicry Literacy Schedule (*)

APPENDIX- SECTION II

II.A.1: Graphical Map of Existing Technologies
II.A.2: Master spreadsheet of Existing Technologies (*)
II.B.1: Outreach Material for Survey Request
II.B 2: 500+ identified quality bio-inspired professionals (*)
II.B.3: Practitioner Survey
II.B.4: Survey Results (*)
II.B.5: Surveyed People of Interest (*)
II.B.6: Near Future Project Pursuits Resulting from Market Research (*)
II.C.1: Geoff Tim's Literature Review
II.C.2: R1 Research Insititutions

APPENDIX- SECTION III

III.A.1: Identifying The Ray's Challenges Systems Map
III.A.2: Challenge Identification and Functional Exploration
III.A.3: List of Organisms for Challenge to Biology Process
II.B.1: Detailed Nature Design Lesson - Zero Carbon - Common stony coral
IIII.C.1: Detailed Nature Design Lesson - Zero Deaths - Big-headed ant
III.D.1: Detailed Nature Design Lesson - Zero Waste - The beaver
III.E.1: Challenge to Biology Paths - Identified Relevant Functions

APPENDIX- SECTION IV

IV.A.1: Life's Principles
IV.A.2: Demonstration of Asha Singhal's Life's Principles Auditing Tool (*)
IV.A.3: Arcade Providence: Example of Life's Principles Auditing Tool
IV.B.1: Project Positive
IV.B.2: Can a Carpet Factory function like a Forest?
IV.C.1: Example Genius of Place Report
IV.D.1: Example Bio-Brainstorm Spreadsheets - Zero Deaths, Zero Carbon, Zero Waste
IV.E.1: National Academy of Science Nature Based Solutions Study
IV.F.1: Life's Principles Leadership Training and Card Deck
IV.F.2: Mapping an Organization as an Ecosystem
IV.F.3: Healthy Thriving Ecosystem Map
IV.F.4: Adaptive Cycle Training
IV.F.5: Immature vs Mature Ecosystem Characteristics Mapping

APPENDIX- SECTION V

V.1: Preliminary Feasibility Study (*)
V.2: Team Bios 2021
V.3: Geoff Timms
V.4: Nicholas Heier
V.5: Michelle Fehler
V.6: Catalina Bustillo
V.7: Flavia Bisi

(*) (all links marked with stars contain internal information that may be available upon request. Please contact *biomimicry@theray.org* if you have any queries regarding this information

THANK YOU

BIOMIMICRY ON THE RAY

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THE RAY