# Low-Cost Technology Initiative Summary Report

## Synchro Co-design Session IV

**October 12, 2023**

**Purpose**: Understand the perspectives of practitioners developing and using low-cost technology.

**Objectives**:
- Gain collective understanding of the low-cost technology field: current examples, applications, challenges, opportunities;
- Converge on a suite of concepts about promising technologies: mechanisms for overcoming challenges, pathways for delivering feasible/impactful solutions;
- Identify how best to connect the broader community and coordinate across the network.

## Pre-Session Survey

Prior to this session a survey was sent to the invitees and shared through LinkedIn. The purpose of the survey was to formulate initial insights into low-cost tools' strengths and weaknesses, and determine standard terminology for this initiative. The survey received 31 responses, which are summarized below.

*Definition of "low-cost technology"*
Refers to tools, devices, or systems that are designed, developed, and priced to be affordable and accessible to a wide range of users, particularly those with limited budgets such as early career scientists, small research groups, or community science organizations. These technologies aim to significantly reduce the financial barriers associated with scientific research and data collection, enabling broader participation and engagement in various fields.

The "cost" of a technology shall refer to a combination of the initial purchase price of hardware and how much effort (i.e. labor, maintenance, calibration) the hardware requires in order to yield sufficient data. For the purpose of this initiative, low-cost technology can span the following types of tools:

1. *DIY kits*: typically do-it-yourself kits offer extreme low material costs, yet require significant effort to function. Open source instructions for building these tools can be found online or ordered as a kit ready for assembly. Materials can be sourced from a user's local hardware store or Amazon at a very low purchase price. However, the burden of assembly,operation and maintenance is mostly on the user. A user's technical abilities vary, DIY technology is generally adopted by users with the time and skills to do this work. Examples of these systems include: openROV, openCTD, etc.

2. *Ready-made low-cost technology*: in general these technologies have been developed and manufactured by a company or research organization. These technologies feature low-cost materials and a user-friendly interface. These technologies mirror existing high-end technology historically reserved for well funded research, yet simplified for a positive user experience and a compromise in data precision for lower initial cost. Examples include: Spotter buoy, hobo loggers, aerial drones, Castaway CTD, etc.

3. *High precision, low effort*: for users not wanting to compromise on data precision, there is a class of technology which still features high quality sensors packaged in a simple/user-friendly system. Examples include: miniDOT, RBR, YSI, etc.

It is difficult to assign a price target for low-cost technology. Typically, many institutions consider any purchase below $5000 per unit as a non-capital asset, which could serve as an upper limit low-cost threshold. However there can be instances of costlier technology, which are still significantly less expensive or easier to use than the leading high-end technology available. Many survey respondents capped low-cost technology at $1000 per unit. Synchro recognizes the economic complexities that all users must consider when procuring tools to enable their data collection. Synchro also recognizes that there is a fitting tool for every task and budget. Synchro will make every effort to prioritize procuring low-cost technology within the spectrum discussed above.

*What makes low-cost technology successful?*
The success of a low-cost technology hinges on its ability to provide accurate, reliable, and meaningful data in an accessible and user-friendly manner. While compromises might be made in terms of precision, successful low-cost sensors strike a balance between cost-effectiveness and data quality, allowing researchers to gather valuable insights within their budget constraints. In general, promising low-cost technology shares the following attributes:

- Accuracy and Reliability
- Ease of Use
- Robustness and Durability
- Calibration Stability
- Minimal Maintenance Requirements
- Data Compatibility and Connectivity
- Modularity and Customization
- Open Source and Transparency
- Affordability
- Scalability
- Compatibility with Existing Infrastructure
- Validation and Comparability
- Support and Community

*What makes low-cost technology unsuccessful?*
Unsuccessful low-cost technologies often suffer from issues related to accuracy, reliability, usability, compatibility, support, and overall fit for purpose. For a low-cost technology to succeed, it needs to address these challenges and provide researchers with valuable, trustworthy, and user-friendly tools for their scientific endeavors. In general, problematic low-cost technology exhibits some of the following characteristics:

- Inaccurate or Unreliable Measurements

- Lack of Calibration and Validation
- Limited Durability and Robustness
- High Maintenance Requirements
- Lack of Compatibility
- Complex or Unintuitive Operation
- Limited Data Sharing and Interoperability
- Insufficient Support and Documentation
- Weak Scalability
- Lack of Data Comparability
- Short Lifecycle
- Limited Data Insight
- Misalignment with Research Needs
- Negative User Experiences

*Concerns about data accuracy & precision*
Responses were mixed regarding concerns about low-cost technology's data accuracy or precision. On one hand, many ocean observing programs - in particular programs that have a long historical time series - require high precision and accuracy to maintain data comparability. Thus, in this context the trade-off between cost and data precision may not be appropriate. On the other hand, trading precision for a lower cost would enable a more broad spatiotemporal coverage of certain variables. Within this context, low-cost technology would satisfy a growing demand for data to answer some of our biggest questions. For any research question, tools need to be fit-for-purpose. I.e. tools need to have a reasonable chance of being effective towards meeting intended needs. It is important for the technology user to make sure they're selecting a technology that adequately meets their data needs for accuracy and precision. For example, observations of day-to-day ocean weather can have relaxed requirements compared to detecting long-term climate change. Furthermore, it's crucial for the technology developer to validate data produced by their technology to ensure it meets their own stated specifications.

*Low-cost technology users and impact*
Two pre-survey questions yielded similar answers, so those are grouped together in this section. Those questions were: 1) who are the primary users of low-cost technology; and 2) where would low-cost technology have the greatest impact? The good news is there are plenty of use cases and demand for lower priced technologies in ocean observing and more accessible data to answer broad questions. Some use cases included: more data available for modeling/forecasting large scale processes (e.g., harmful algal blooms and marine heatwaves); enhanced situational awareness for improved response to environmental disturbances; and acquiring new data to elucidate the compelling nature of the ocean and its many secrets.

Low-cost ocean observing technology would have the greatest impact within the contexts of community science, early-career scientists, government and non-government organizations, and commercial enterprise. In general, entities which lack specific technical expertise and consistent/abundant funding will benefit most from a low-cost and user-friendly piece of technology. The Blue Economy is growing at a rapid rate. Therefore, assessments of human impacts on the ocean - and ocean impacts on society - should also grow. The Global Ocean Observing System serves important data to biogeochemical, climatic, and ecosystem level ocean processes at coordinated regional scales; yet local knowledge gaps and key questions remain. Smaller groups are beginning to assess these data gaps and identify additional problems to be addressed. One promising avenue is integrating low-cost technology into programs and platforms of opportunity (e.g., combining efforts with existing initiatives and other ocean users).

‘Community’ was a recurring theme of this co-design session. Participants recognized that - historically - ocean science, research, and economic development have been siloed within their own use-cases, institutions, and operational requirements. However, the growth in the Blue Economy is outpacing traditional ocean science entities' ability to answer certain questions. There was general agreement on a community coalition approach to monitoring for impacts and planning strategically among competing priorities.  Further, communication and collaboration among groups; accessibility of data; and efficient dissemination of results were all highlighted as mechanisms for impact and success.

Please see the appendix for a list of specific “low-cost technologies” mentioned in the pre-session survey and throughout the session.

## Session IV - Low-cost Technology Procurement Co-design Session

| Setting the stage with Low-Cost Tech lightning talks:<br>Lessons and success stories, initiatives, citizen science, user perspectives, development and manufacturer perspectives |
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| Oceankind & Marine Technology Society’s perspective, Justin Manley |
| SMTP’s priorities for low-cost tech, and how success is defined, Erika Montague |
| Deep & Cheap Initiative, Jessica Sandoval |
| Testing and evaluation for Alliance for Coastal Technologies (ACT) with a focus on low-cost technology, Mario Tamburri |
| Development and manufacturing of low-cost tech, Shah Selbe |
| Demand for low-cost technology from a user perspective, Colin Bowser |
| Development of and needs for low-cost tech, Manu Prakash |
| Development/use/ongoing refinement of the GOA-ON in a Box kits, Alexis Valauri-Orton |

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| Low-cost tags, Barb Block |
| Reef Check: citizen science and low-cost tech, Dan Abbott |
| Low-cost tech and how NOAA uses it, Ann-Christine Zinkann |

**Breakout Session 1**
In this breakout session co-design coordinators organized multidisciplinary groups to pick 3-4 categories of technology from a larger list and rank those technologies on axes of ‘impact’ and ‘feasibility’. Synchro defines ‘impact’ as in the benefit or value a particular technology brings to ocean observing data acquisition efforts and priority essential observing variables; and ‘feasibility’ as in viability of adoption and long-term use in terms of cost and effort. Considering them together enables one to compare technologies and prioritize.

Participants selected the following categories of technology to rank, listed in no particular order:

*AI Classification*
Artificial Intelligence (AI) I has the ability to reduce data classification effort for acoustic and imagery data, through event detection and categorization. Participants ranked this as high impact and high feasibility. AI is creeping into many aspects of our daily lives, driven by the growing need for faster information processing and enabling decision making. “More data, more often” is the mantra of most information users, including within the context of ocean observing. In particular, with the adoption of more acoustic and imagery data collection modes in parallel with increasing labor costs, AI will enable more rapid assessment and categorization of those types of data. There are plenty of use cases for AI in oceanographic data processing, such as remote platform-based processing of large datasets for compressed data transmissions over satellite networks.

*Connectors/Modularity*
Standardized and/or robust connectors would improve sensor integration and modularity. Participants ranked this as high impact, but low feasibility. A low-cost connector which enables flexible, plug & play integration of systems on platforms would be welcomed by marine technicians. However, participants acknowledged that this scenario would be very challenging without regulatory initiatives to mandate standardization of connectors across the sector.

*Ocean Acidification & Hypoxia Measurements*
Tools for measuring seawater pH, $pCO_2$, alkalinity, and dissolved oxygen. Participants ranked this as high in impact, but medium in feasibility. Ocean acidification and hypoxia threats to sensitive species is a great concern associated with the impacts of climate change, thus any low-cost technology produced would have an impact on the ability to understand these processes. However, the group recognizes that these variables are difficult to measure - with high enough accuracy, precision, and reliability - at a low cost.

*Passive Acoustics, Tags, & Telemetry*
Tools for listening for animal calls and logging animal tag detections. Participants ranked these as medium to high on both the impact and feasibility scales. Measuring underwater acoustics is a straightforward technology, which generally lacks spatiotemporal richness due to limited deployment platforms. Therefore lower cost and accessible technology could enable more piggy-backing on existing offshore platforms, ships, and even animals themselves. Though it was noted that data generated from these tools can be voluminous and challenging to transmit over satellite telemetry without some onboard processing, which is still an emerging technology.

*Microscopic Imaging*
Tools enabling imagery collection of zooplankton and phytoplankton. Participants ranked this as medium to high impact, but medium to low feasibility. *In situ* microscopic imagery is an exciting emerging technology which enables a higher resolution of species identification at the lower ends of the ocean food web. To date there are over a dozen options available for this type of technology, new and lower cost options would have significant impact. However, participants acknowledged that existing technology examples are often complex to work with and that the road to low-cost and easy to use could be a long one. Though any incremental enhancements to this type of technology would attract interest from the ocean observing community.

*Water Samplers*
Tools for enabling in situ seawater collection and processing. Participants ranked this both high in feasibility and impact. Enhancing the ability to collect and preserve multiple discrete water samples with a simple to use in situ system would be very beneficial, as this tool would support many use cases. The development of a low-cost and easy to use tool is highly feasible because many of the individual components are readily available. Furthermore, resulting data would be compatible and comparable with previous and ongoing user efforts.

*Biomolecular/eDNA*
Tools for enabling collection and analysis of eDNA. Participants ranked this as high impact and medium feasibility. Emerging technology and protocols for eDNA are exciting for their ability to capture biodiversity and presence/absence in new ways, making this technology high impact. However, eDNA methods are still rather complex and can require expensive equipment (or sending samples to suitable sample processing vendors); and output data require a well-trained eye to be interpreted properly. Thus, participants placed eDNA as a low cost option at medium feasibility. Though any incremental enhancements to this type of technology would attract interest from the ocean observing community.

*Nutrients*

Tools for measuring i*n situ* nutrient concentrations in seawater. Participants ranked this as high impact and high feasibility. The ability to measure nutrients (and perhaps also trace metals) as they pertain to primary productivity has historically been challenging and expensive. New *in situ* probes and chemical analysers for nutrients are coming out on the market, but are still expensive. Broad technical advancements in miniaturizing/simplifying spectrophotometric and colorimetric components will make low-cost nutrient analyzers more feasible. In turn, these technologies would support a broad spectrum of use cases across multiple industries.

*Antifouling*
New methods for reducing fouling of ocean observing hardware and enabling longer deployments. Although not officially ranked, two groups mentioned antifouling as a high impact target. Biofouling is a great impedance to long-term ocean observing efforts, especially further offshore where regular maintenance is difficult.

**Breakout Session 2**
The second breakout session was focused on discussion questions to hone in on important considerations for the procurement call.

*What priority data gaps exist and how might low-cost technology fill those data gaps?*
Society's insatiable appetite for up-to-date and detailed information at our fingertips drives technological innovation. Nonetheless as we fill the information gaps of last year, we are identifying information gaps for next year. Broadly, low-cost technology has the ability to close spatial and temporal gaps in already ongoing ocean observing initiatives (i.e. data for everything, everywhere, all of the time). For example, passive acoustic arrays are great for tracking vocal marine mammals in a region and that information is important for a lot of reasons. However, if one acoustic sensor has a listening range of ½ mile radius and may only listen for 15 minutes out of every hour due to power constraints, then those gaps become very apparent. It would be impractical to cover the entire ocean in low-cost and low-power acoustic sensors; but identifying priority variables, priority regions, priority seasons and appropriate deployment periods which would be highly feasible at producing highly impactful results can provide more of the actionable information society needs. Below are some priority focus areas mentioned by the participants.

*Coastal Zone*. Ironically, the near coastal zone is where the most people use the ocean, yet is arguably lacking the most data.

*Marine Carbon Dioxide Removal (mCDR)*. Private companies and investment entities are rapidly jumping on the mCDR bandwagon without fully considering the environmental impacts or how to assess those impacts.

*The Deep Ocean and Seafloor Mapping*. While we know relatively little about the deep sea, its vast areas are being considered for industry activity including seafloor mining and offshore wind industry development.

*Pathogens/microbes*. The ocean science community was shocked when in the span of a month in Fall 2013, sunflower stars along the North American Pacific coast suddenly disintegrated and a decade later we are still dealing with the ramifications. What else is lurking out there that could be equally devastating?

*Offshore development and resource extraction*. Commercial entities view the ocean as an infinite resource bonanza, while government agencies need to regulate those entities to achieve sustainable extraction and minimizing impact. Those agencies rely on the "best available science" to make informed management decisions.

*Harmful Algal Blooms*. The mechanisms for how they're triggered and distributed is not well understood.

*Ocean Acidification and Hypoxia (OAH)*. OAH is a profound outcome of climate change likely to have differential impacts on many species and at different life stages. Because OAH is widespread broad biological impacts- on top of the fact that measuring the problem requires high precision and nuance - our ability to address this presents a monumental challenge.

Participants in this session also pointed out that using low-cost technologies to fill the above data gaps will require a more coordinated approach to data management. For the 'community' approach discussed earlier, there needs to be a freer flow of information between groups. Participants encouraged upholding metadata, data format standardization, expression of error, and data quality control protocols. There was also encouragement for more backend support for data repositories to ensure more efficient queries and crosswalking relational datasets.

*What are some promising approaches for enhancing synchronization between technology manufacturers and users?*

Participants offered a broad range of excellent ideas for motivating the uptake of low-cost technology in an operational environment. Namely, improved communication and coordination between technology developers and users; making technology easier to use; and exploring different business models for hardware success.

It's emboldening for Synchro's existence that participants mainly pointed to 'communication' as the best method for synchronizing users with technology development efforts. Synchro's goal is to grease the gears between science, technology developers, and information users. Communication is an important component to achieve that goal. Following are some examples mentioned in this session:

*Facilitating Interactions*: some of the silver-linings of Covid were the realizations that face-to-face communication is key. When work shifted to remote for two years and we all saw the monumental shift to video conferencing as a preferred communication mode over phone-calls and emails, we greatly improved our ability to connect with people across the country and across groups. And subsequently many people returned to work with a stronger appreciation for in-person communication, though conversely many other people prefer *less* in-person communication after Covid. The point is, humans are inherently a social species and getting folks together to chat, brainstorm, share, smile, and furrow their brows on a common goal yields the best results:

- Webinars
- Workshops
- Conferences
- Informal discussions
- Co-design
- Interdisciplinary meetings
- Tech focused groups/Slack channel

*Iterative development*: every technology developer should already be doing this, but frequent communication with users through the development phase is crucial, especially in the commercialization phase. The Agile Development method is essentially: plan, develop, evaluate, repeat. Within the ‘evaluate’ component, developers should be having their technology tested and evaluated by potential users and consider their feedback. Synchro provides these services. Every technology developer must understand their user’s pain-points: 1) is your tool solving their problem?; 2) is your tool better (easier/cheaper) than other tools?

*User needs*: wherein developers need to ask the right questions of their users; users need to give clear answers. The market for ocean observing technology is small and niche, but projected to grow with the overall Blue Economy. In order for a low-cost technology startup to capture a portion of the market, they need broad adoption; and broad adoption is achieved when a large user base has similar requirements and use cases for a technology. Improved coordination between different user initiatives would be beneficial to the development of technology.

*Technology Marketing*: though not discussed in this session, but it was talked about in previous co-design sessions; many users find new technology by word of mouth which is an inefficient mode of marketing. The Alliance for Coastal Technologies offered through their website a comprehensive database of ocean observing tools which any user could parooze and ‘shop’ for technology. A desire was expressed that someone create an Amazon-esque platform of ocean observing technology with customer reviews, FAQs, and a community of users?

Next, participants highlighted that the smooth operation of a technology would improve user uptake. “Make it easy to use!” Users want a modern user interface and a straightforward - yet complete - user manual. Youtube videos of important manufacturer recommendations (e.g., calibration method, simple parts/battery replacement, readying for deployment, care &

maintenance, short or long-term storage, biofouling strategies, etc). Can the hardware be operated via a mobile application to reduce the amount of gear taken into the field?

Finally, participants suggested a few business model ideas (outside of business to consumer sales) for scaling technology uptake, from a developer perspective:

1. *Operate the asset and sell the data (a.k.a a 'data buy')*. Users are mostly interested in the data and there could be real value to them in not having to buy and maintain a capital asset. The manufacturer is likely to take better care of a technical piece of hardware than the user, plus the manufacturer has the in-house knowledge and tools to maintain a fleet of hardware.

2. *Hardware as a service contract*. The manufacturer owns the assets and employs the staff to operate and maintain them. Allow the users to choose their own adventure with regard to desired data outcomes.

3. *Equipment lease / rentals*. Oftentimes equipment is purchased and used for short durations (e.g., days to weeks). Offering the option to rent tools could be attractive to some users.

*Of the potential pitfalls of low-cost technology, what are your deal breakers?*

During the pre-survey we asked respondents to list any pitfalls of unsuccessful low-cost technologies. Those results are discussed in the section above. In this session, we asked for more specifically what characteristics are a 'hard no.'

The most mentioned deal-breaker for low-cost technology is unreliable data. In order to be successful at their job, users need to have confidence in the data they're collecting. The single most annoying situation is looking at one's hard earned data and wondering "is this right?" Real-world decisions are based on data, so data reliability is paramount. Both the user and manufacturer should be responsible for the hardware's data output. The manufacturer is responsible for validating data and determining appropriate accuracy/precision specifications; also ensuring data stability over time by recommending appropriate operation and maintenance schedules. The users are responsible for selecting the right hardware for their use case and then treating the hardware in the way the manufacturer intended it. Technical support and communication in problem-solving between the user and manufacturer will promote user confidence in both the hardware and the organization that produces it.

The next most mentioned deal-breaker was a negative user experience. The hardware breaks too often; the user interface is too complicated; poor customer service; the hardware is difficult to work on or parts are difficult to get; long periods of service down-time; documentation is lacking in clarity or detail. Owning any tool that the user loathes to use, guarantees that tool will not be used for long.

*Which low-cost technologies could enhance the effort of select community science entities?*

In the survey we asked respondents to list contexts where low-cost sensors could have the most impact. The dominant response was 'community science.' In an effort to get more specific and to help shape Synchro priorities for the low-cost procurement program, we asked for specific examples of successful pairings of community science organizations and low-cost technologies. Here are select cases:

> Carbon to Sea Initiative: is a group with the mission of evaluating Ocean Alkalinity Enhancement (OAE) methods as a means to repair atmospheric carbon pollution and understanding the impacts OAE has on local communities and environments. As a subset of mCDR methods, OAE employs principles of geoengineering to ramp up the carbon cycle in localized regions through various methods. This group would benefit from low-cost technology that gathers ocean acidification measurements (pH, alkalinity, pCO2) in seawater.
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> Ocean Census: is a group with the mission to catalog new species in the marine environment. They suggest that humanity has only discovered about 10% of all the oceanic species and that we can't protect what we don't know exists. This group would benefit from all types of recorded imagery tools, including microscopic and hyperspectral.
>
> Reef Check: is a group with the mission to conserve rocky reef habitat by using citizen scientists to collect ecosystem data about them each year. More recently, Reef Check started collecting temperature, pH, and dissolved oxygen data with sensor deployments. Reef Check would benefit from low-cost video & still imagery tools and perhaps passive acoustic monitoring sensors.
>
> Beach Combers & SurfRider Foundation: both of these groups walk along beaches in organized volunteer events to look at dead things or pick up trash. This group would benefit from low-cost tools that would enhance their trash collection efficiency, but also any tools that could piggy-back on their efforts which could fill gaps in the shoreline zone.
>
> Citizen Science harmful algal bloom monitoring: there are quite a few volunteer organizations focused on HAB monitoring. These groups would benefit from low-cost microscopic imaging systems and low-cost water quality monitoring tools.
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> Alutiiq Pride Marine Institute: is a group based out of Seward, AK with focuses on shellfish mariculture, kelp farming, OAH and HAB monitoring, water sample analysis for the benefit and prosperity of indigenous tribes in the region. This group would benefit from all categories of low-cost technology.

**A developer's success in assessing product-market fit of their technology benefits everyone. Know your customers and know their use cases!**

Final Thoughts

Synchro is currently hosting an open call for technology developer applications to test and evaluate their prototype technology on existing ocean observing platforms around Monterey Bay and British Columbia. This service is offered at no cost to the developer. Synchro has streamlined the process of getting a piece of hardware promptly deployed on a platform by coordinating with the platform provider's management and technical team. Following a successful evaluation, Synchro (at the consideration of the developer) will promote the prototype on our website and to The Synchro Network - a growing network of international ocean information users.

By the end of this year, Synchro will be putting out an open call for low-cost technology quotes. Synchro intends on procuring quantities of low-cost technologies from multiple priority categories such as biomolecular/eDNA, imaging, passive acoustic monitoring, and animal tagging. Selected technologies will be ordered and delivered in 2024. Procured technology will be distributed to information users with The Synchro Network for operational use, testing and evaluation.

Thank you for taking the time to review these insights into the landscape of low-cost technology.

Sincerely,
Synchro Co-Design Team

## Appendix

List of Low-Cost Technologies mentioned by participants in the pre-survey and in the session. Inclusion in this section does not constitute an endorsement by Synchro or its partners.

Deep GoPro Housings
Pink Flamingo Sonar reflectors
Southern Fried Science
SoFAR/Spotter Buoy
Phyter
Blue Robotics ROV2
OpenCTD
OpenROV
OpenBuoy
Foldascope
Planktoscope

OpenPCR
Baby Legs
CLEAR Labs
VuLink
Navy Sonobuoys
Liberty16 (qPCR)
Aquasens
DEEPi cameras
ICE LEDs
Fiber Optic Microtether
Aerial drones
Maka Niu
Vaquita (Paralenz)
Open Ocean Camera