Breakthrough Energy Fellows EXPLORER Funding application, due 8 Nov 23 Alaska Applied Sciences, Inc.

Following is text entered into the on-line application form, **in response to instructions, in blue.**

Proposal Overview

Durable, low-cost (CAPEX, OPEX), low-Earth-impact (GHG emission, embodied energy) construction system for small buildings (shelter, housing, storage): quasi-spherical thin-shell concrete (1-2 cm thick) envelope, for rapid on-site construction with minimum imported materials, tools, and expert labor. Neither foundation nor roof is required, to endure the looming Global Climate Change weather extremes of temperature and storms, with a great saving in concrete per enclosed square and cubic meter.

We achieved scale model proof-of-concept in 2010 in Juneau, Alaska, including the following 13-year weather exposure with minimal damage; simple testing for full-Earth-burial strength and seismic shock endurance for disaster recovery and war zone survival as well as for low-cost shelter and housing, for global markets.

We're ready now for scale-up to human-useful size, for further design advances and testing for building codes and permitting; to build demonstration models, for discovering and building markets.

We now require $ 600,000 external cash; $ 500,000 from Breakthrough, please, by which we can leverage the rest.

Short Answers

Innovation and Impact

Please describe your technology solution in detail. Feel free to paraphrase the broader climate challenge in a sentence or two but assume that your audience is technical and understands the climate context.

What specific problem are you solving?
Please explain how your technology solves a specific industry issue and how it is transformational. For example, please do not respond "climate change", "energy storage", or "clean hydrogen".
If successful, what impact will your technology have on the industry status quo? On carbon emissions?
Do you have any proof-of-concept results and what have they demonstrated?

Earth's Global Climate Change (GCC) emergency requires humanity to stop building costly, complex, weak, flammable, toxic, small buildings, for shelter, housing, and many other uses, to invent and adopt structures to withstand weather extremes, fires, seismic shocks, and protective total Earth burial -- using little material and energy, with light Earth impact. Quasi-spherical -- limited to large radii of curvature -- thin-shell concrete small buildings are ideal; we must develop a rapid and economical and benign construction methods and materials system for them. That's the problem we are solving.

Please see our scale model, proof-of-concept, thin shell concrete structure work in Juneau, AK, 2009-2023:

> https://vimeo.com/828631285	Thin-shell Concrete, Low-Earth-impact, small buildings
> https://vimeo.com/880814295	Refurbishing 2023:
> https://vimeo.com/758580425	Thin-shell Concrete Quasi-spherical Buildings for Durable, Low-cost, Low-impact Shelter, Volume Production

> www.AlaskaAppliedSciences.com/thin-shell-concrete-structures

We have demonstrated, at about one-third human-useful scale, the Earth-protection advantages of this construction method, materials, and special tooling, for small buildings, including housing, anywhere:

1. Very small amount of concrete, thus "cement" is required. The prototypes are ~ 1 cm thick; full-size buildings will be < 2 cm thick. Novel, GHG-emission-free or -neutral, cementitious materials should be compatible, reducing embodied energy.

2. Foundation ring pour is fast and easy, with light vibration; forms set assembles and removes quickly; lifting lug bolts cast into ring enable transport, for small buildings; heavy fiberglass tie-in mesh is cast into ring.

3. Curved "orange peel" forms segments bolt together quickly, with a shim in every joint, and Teflon sheet panel coating are keys to fast, easy form set removal from cured shell; no form oil; but, need to invent a foolproof vibration consolidation method.

4. Chomarat "C-Grid" is designed, tested, and accepted as primary reinforcement for concrete; easy and fast to install by SS stapling to the EPDM rubber covered, Teflon-sheet-coated, form panels; modest cost; no corrosion.

5. Closed-cell UR foam is then easily sprayed onto raw interior of thin concrete shell, to desired thickness. Because we have no "thermal bridging" from structural wood, a few cm of foam is far more effective than it would be in a stick-built building; it is the interior vapor barrier, adds structural strength, and seals any openings. In the full-size "houses", it will encapsulate the wiring and plumbing. A thin coat of plaster must be sprayed upon the foam, to protect people and foam from each other. Foam and plaster are benign and compact materials.

6. We adapted the "dome" shape to accept door, arctic and mudroom "entry", window and skylight installations, and mock chimney and plumbing vent adjuncts compatible with the structural integrity of the quasi-spherical, large radii of curvature, monococque building design. This is the enabling production method, materials, and tools.

7. We tested the 1 cm thick prototype, scale model buildings for durability in two ways: (a) Complete burial in sand, with 1 m of sand on top, without visible damage, while interior dial indicators showed that the dome height decreased by 0.010" and increased in diameter by 0.010"; asymmetric sand removal did not cause visible damage; (b) Three repeated horizontal ~ 2.7 g shocks to a wire rope around the foundation ring, delivered to a slacked chain by a large front end loader, did not produce visible damage. We concluded that these prototypes were very strong, robust, and resilient, in spite of our failure to consolidate the wet concrete, via vibration to the one-sided form, upon concrete placement.

In Spring 2023, after the first prototype dome had sat in the Southeast Alaska woods for 13 years, we cleaned and refurbished it, to discover what damage it had suffered.

After scraping off ~ 3 cm of moss and pressure washing, the exterior concrete surface had weathered < 0.5 mm. It readily accepted coats of concrete primer and paint. We found no evidence of leaks on the dome interior; the thin plaster coat was still intact; we painted it. The manufactured flooring was in good condition, although the building had no door, and no heat or occupants, those 13 years.

Thus, our proof-of-concept results demonstrated that scale-up, to human-useful size, of this small building design, would probably be very practical, useful, economical, strong, durable, of long service life, fire-repellant, earthquake-resistant, and Earth-shelterable -- at about this minimum size range:

- 2.5 m radius, 5 m diam, 3 m height from floor to apex, stretched to "bratwurst" shape
- Floor total area ~120 sq m, of which center section rectangular area is ~ 48 sq m, plus small loft

Transport, moving, and assembly of the one-side concrete form set is safe and convenient.

Project Goals & Risks

Breakthrough Energy Foundation supports early-stage climate technologies that VC is often unwilling to support due to perceived technical risk. The Explorer and Innovator grants provide funding, technology management, and programming support to minimize those risks and generate technical proof points.

- **What do you aim to achieve by the end of the program period from a technical and commercialization perspective?**
- **What core technical risks currently exist for your technology; how will you address them during the program?**

Technical:

1. Design and build three tools (molds) upon which to manufacture complete sets of single-side male forms, upon which to construct the full-size thin-shell concrete buildings.
2. Manufacture two complete forms sets, by which to build thin-shell concrete structures of a limited range of human-useful sizes and shapes.
3. Demonstrate which GHG-emission-free "green" cementitious materials are compatible: provide adequate thin-shell concrete strength and resilience, with C-fiber-grid as primary reinforcement.
4. Measure working and ultimate strength and resilience of human-useful-size thin-shell concrete buildings < 2 cm thick, with (a) isotropic loading; (b) asymmetric distributed loading; (c) horizontal seismic shocks.
5. Design the vibration consolidation system to eliminate air voids in the thin concrete shell.
6. Design several window and door framing systems to maintain monococque distributed strength in the thin-shell concrete structure, while accepting standard window sizes.
7. Decide how to install simple plumbing and wiring inside the concrete shell, "to code", while encapsulated by interior sprayed closed-cell UR foam insulation.
8. Design and build special tools for speed and safety with this unusual building production system: curved ladder to reach exterior apex for reinforcement C-Grid stapling and following mortar placement on assembled form.
9. Measure thermal performance of the building; determine HVAC system loads, candidate heating, cooling, and air quality maintenance system types; automatic CO2 control.

Commercial:

1. Obtain building permits for one or more full-size homes, from engineering analyses funded by this project.
2. Build one or more complete, finished, occupancy-ready, full-size, small houses as "model homes" to (a) sample public response; (b) produce advertising videos, print materials; (c) find customers -- persons, builders, developers -- to purchase or lease forms sets, custom materials, and crew training. Sell the homes.
3. Discover and strategize how to overcome human resistance to adopting and choosing something so "new", "unconventional", and risky, to reach (a) billions who have nothing better; (b) millions who find them affordable, attractive, and safer than "stick-built"; (c) enabling banks, appraisers, insurors, engineers, building officials.
4. Develop DRAFT candidate business models by which to grow the company to good profitability.
5. Develop a cost model by which to price our company's products; by which the company's customers can price the buildings they will build and sell, with the tools and materials we supply.
6. Discover obstacles to company success and growth; to this building system's fundamentals:
    a. Building officials, municipal and state, national and international.
    b. Bank lending: construction and mortgage loans; appraisers.

Core technical risks:

1. Quality control for all aspects of on-site thin-shell concrete structure:
    a. Quality of on-site available water and sand
    b. Installation of "C-Grid" primary reinforcement tiles: "C-Grid" quality; overlap; stapling
    c. Batch and mix concrete mortar
    d. Placement of concrete mortar: quantity, thickness, forcing it into C-Grid, encapsulate upon form
    e. Vibration of the form and mortar, to eliminate air pockets
    f. Tooling and finishing of mortar outer surface
    g. Maintain wetting of mortar surface during two-day cure; wrap in curing plastic or sprayed resin

    How to address risks:

    - Establish and edit procedure (document with photos) plus training video(s)
    - Standardize C-Grid tile size; stripe each side with overlap distance for placement
    - Invent vibration system integral to each panel of forms set, with electric drive system
    - Experiment with manual (trowel) and mechanical (pump, spray) mortar placement

2. The forms set panel coating system used for prototype, 13 years ago, may be inadequate for volume, many-use production: (a) 60 mil EPDM rubber sheet stretched and glued to fiberglass panel exterior; (b) 3 mil Teflon sheet with 5 mil butyl rubber adhesive, stretched and self-fastened to EPDM.

    How to address risk: Experiment with other coatings capable of (a) capture ends of SS staples used to fasten C-Grid to panel, and (b) release panel from interior of cured concrete thin-shell. Goal: Single sprayed coating, easily applied in optimized thickness, achieving both functions; easily refurbished after many buildings.

3. "Monococque" [1] inherent strength; foundation-free deployment:
    a. Goal is a "monococque" structure integrating the foundation ring and thin-shell concrete shell as a single piece able to (a) safely bear all applied loads -- generally isotropic loads -- mechanical and thermal (fire, of limited duration and temp), and (b) transmit the cumulative and instantaneous (seismic) loads to the Earth on which the building is placed, (c) in all weather conditions and seasons, (d) without a discrete "foundation", (e) where soil conditions beneath the building are not ideal.
    b. We need a simple, inexpensive Earth-coupling, Earth-support system by which the monococque is supported without stress concentration.

    How to address risks: Experiment with, and invent, practical Earth-coupling system(s) via FEA and other engineering analyses; prove, and improve over time.

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[1] Monococque: an aircraft or vehicle structure in which the chassis is integral with the body. Also called structural skin, is a structural system in which loads are supported by an object's external skin, in a manner similar to an egg shell. First used for boats, a true monocoque carries both tensile and compressive forces within the skin and can be recognized by the absence of a load-carrying internal frame.

Technology Context

Use this section to describe how your proposal fits into the broader industrial context. You should discuss any competing solutions, alternative approaches, or potentially competitive products/services. You may also want to highlight the role of policy and regulation in the deployment of your technology.
Identify and briefly describe the incumbent technology and competitive landscape
How is your technology differentiated from others in the space? What gives you confidence in your solution? Why now (especially if innovation in this sector has been attempted before)?
What technoeconomic barriers could your technology potentially face?

Industrial: Humanity needs affordable, durable, low-Earth-impact housing -- and shelter and storage, of all types and sizes -- that minimize embodied and operating energy and that will protect occupants from future severe weather and wars driven by Global Climate Change (GCC). Our design and production method elegantly achieves that, anywhere on Earth, via quasi-spherical, thin-shell concrete small buildings which minimize CAPEX, OPEX, and GHG release, and:

- Minimize lifetime Earth impact in many ways;
- Are resistant to fire, earthquake, storms, tsunami, T extremes, corrosion, rot, vermin, and war -- if Earth-sheltered, to stop small arms fire and shrapnel; have no roof to blow off;
- Minimize mass, volume, and cost of materials and tools imported to building site -- per building, per m^2 and m^3 of building; use local sand and water for the concrete mortar mix;
- Minimize imported skilled labor;
- Minimize envelope construction time to "enclosed";
- Need no heavy or high-powered equipment; no ready-mix, blocks or bricks;
- Need no costly foundation for Earth-coupling; many floor options, from dirt to insulated;
- Easy plumbing and wiring; modular kitchen and bath options;
- Provide useful loft floor space and volume;
- Are ideal for on-site build, except for very small buildings, which may be also be transported;
- Deliver very long service life; reduce recurring maintenance and CAPEX;
- Are easily insulated, to any required level, by internally sprayed closed-cell UR foam;
- Are strong enough for Earth berming or complete Earth burial; enhanced protection from all threats;

Competition, alternatives, incumbents, differentiation:

No incumbent or alternative construction method for small buildings delivers our combination of features listed above, for on-site construction, especially for remote and / or difficult locations:

- Stick-built, including on-site, factory-built, kits, and mobile: costly; high labor content; many components; difficult to insulate well; vulnerable to fire, earthquake, and storms; vulnerable roof; may require transport to site over good infrastructure, with plumb and wire on-site install, plus weather-sealing of modules;
- 3D concrete printing: requires costly printer and mobilization, plus flat site or leveled installation; larger concrete mass and embodied energy than thin-shell; no primary reinforcing, i.e. isotropic tensile strength and resilience throughout the structure. Monocoque structure is difficult to achieve -- cannot print upper region of quasi-spherical (dome) without internal forms support -- which is inherent in our system. Our system provides primary reinforcement by carbon-fiber-epoxy "C-Grid", tiled and overlapped, for a strong monococque.
- Block, brick, rammed Earth box: need nearby block source; difficult to include primary reinforcement, for seismic and storm tolerance; roof vulnerable to blowing off.

Role of policy, regulation, deployment:

- Resistance by banking, insurance, appraisal, engineering firms, building officials.
- As conventional construction becomes costly to insure, thus finance, thin-shell concrete buildings become even more attractive.
- Universal Building Code compliance requires engineering analysis, in-field test data, to enable general acceptance by the construction, regulatory, and housing communities.
- Several business plans are suitable for profitable deployment and proliferation; may need regulation.

Why we are confident in this solution:

- Our scale model, proof-of-concept building and testing in Juneau, Alaska, 2009 - 2023, demonstrated the above principles and features. Janicki Industries, Sedro-Woolley, WA has reviewed the project adequately to give us a rough order of magnitude (ROM) estimate for cost of tooling design and build, plus manufacture of two complete sets of forms on which to build full-size prototypes for engineering validation and architectural design.
- Feedback from construction professionals is generally encouraging.
- We have over forty years experience building "domes" of various construction types.
- Rapidly worsening GCC-driven dangers makes this "shelter" solution increasingly attractive and necessary.

Why now:

- Rapidly worsening GCC-driven dangers makes this "shelter" solution increasingly attractive and necessary.
- USA and the World need affordable, durable, low-Earth-impact shelter and housing. Many disaster sites -- some very remote -- always need help.
- Fundamental principles of physics and engineering reveal several key advantages of quasi-spherical thin-shell concrete buildings.
- Novel GHG-emission-free and / or -neutral cementitious materials are becoming available, by which to reduce whole-structure embodied energy.
- State-of-art tooling CAD and fabrication, and FRP (fiberglass) forms sets production from that tooling, makes a variety of quasi-spherical building shapes available for thin-shell concrete. Morphing from "dome" to "sausage", then to a more rectangular building "footprint", without sacrificing the system's fundamental advantages, becomes possible with experience and acceptance.

Techno-economic barriers:

- Short-term: need scale-up to human-useful-size, to prove advantages and markets: "model home" show-me, touch and feel
- Customer and cultural acceptance of non-traditional shape, landscaping, and lifestyle; peer pressure
- Skepticism by bank, insurance, appraisal, engineering, and building officials communities
- Build a company and industry on the field-proven, matured, high-volume, global enterprise.

Participation in Other Programs

If applicable, please describe any incubator programs, accelerator programs, or competitions that you have either applied for, previously participated in, or are currently participating in related to the technology proposed.

PARTICIPATION IN OTHER PROGRAMS:

Alaska Applied Sciences, Inc. (AASI) has applied unsuccessfully for funding via applications to:

- ARPA-E "Open" FOA, 2018, 2021, both as Concept Paper and as Full Application: https://alaskaappliedsciences.com/wp-content/uploads/FOA-2459-3-E-4261-5Apr21.pdf
- California Energy Commission via EPIC program, 2015 - 2021
- NREL Small Business Voucher (SBV) program, 2019
- 2023 NREL Industry Growth Forum, Denver
- 2023 Smart Cities pitch competition, Denver
- 2023 NSF SBIR / STTR Phase 1 applicant (pending application submission) # 00059033: Advanced Manufacturing (M)
- Launch Alaska's 2023 - 2024 Tech Deployment Track

AASI has self-financed all work on this technology and construction process, to date. AASI has not participated in incubators.

OTHER: Intellectual Property

Please describe your current IP status without sharing propriety information or trade secrets. Identify any currently existing proprietary technologies or intellectual property that you will need to use to meet project goals and describe your ownership or use rights.

Applicants are not required to have sole ownership and control of their proprietary technologies and IP to be selected, but this information will allow us to evaluate impacts on scaling opportunities and to help best position projects to meet their decarbonization goals.

Have you or anyone else filed any patents critical to this work?

OTHER: Intellectual Property

No, we have filed no patents nor applications. We don't know of any patents specifically critical to this work, nor that would interfere with the progress we intend and describe in this application. Patenting anything about placing and curing concrete, in this mature industry, would be futile and a waste of our resources.

Our IP is the "trade secrets" we have developed in our early work, and that we will develop via this Breakthrough project. Our competitive advantage is the synergy of our trade secrets with our market position, when we scale-up our proof-of-concept system to human-useful scale. Our business plans will be built on this synergy. The mature industry will be so large that our company's share of the global market will be very rewarding, in many ways.

VIMEO video https://vimeo.com/880814295

Thin-shell Concrete Structures: Low-cost, Low Earth Impact, Fast Build, Ready for Scale-up to Human-useful Size

Here's our scale model, proof-of-concept, quasi-spherical, thin-shell concrete prototype, built in Juneau, Alaska thirteen years ago at the University of Alaska Southeast Tech Center. Its concrete envelope is only 1 cm thick (1/2 inch), requiring only one-third yard of sand-only-aggregate concrete.

Concrete primary reinforcement is rust-free carbon fiber epoxy grid.

After thirteen years' exposure to Southeast Alaska weather, we refurbished it in 2023 to demonstrate its ruggedness, and that our small company, Alaska Applied Sciences, Inc., is ready to invest in new tooling -- to scale-up to human-useful size -- by which to build sets of one-sided concrete forms on which to build small, low-cost, long-life, strong, durable, fire-and-weather-resistant, small buildings for shelter and housing, schools and clinics and storage, anywhere on Earth -- especially in remote areas and for disaster recovery, where we must minimize the amount of imported materials, tools, and expert labor.

This scale model prototype is insulated with ~ 3 cm (1.5 inch) of closed-cell urethane foam, sprayed onto the thin concrete shell interior, with a thin plaster overcoat to protect people and foam from each other. Even at this small scale, it's a robust, lockable shelter in which a homeless person may feel secure in person and possessions; body heat alone will keep the resident or two warm enough to survive.

The 12-volt DC PV-battery electric system provides LED lighting and phone charging, and operates the automatic ventilation system to prevent dangerous CO2 concentration inside.

We are looking for $ 600,000 of external investment for our company's scale-up project, to prepare humanity for the Climate Change driven severe weather ahead: no roof to blow off; strong enough to be Earth-bermed or completely Earth-sheltered; protection from storms, temperature, fire, tsunami, earthquake, corrosion, vermin, rot, and war -- from small arms fire and shrapnel, if the house is totally Earth-buried.

Many creatures survive, Earth-sheltered; it's our turn.