GAS SEPARATION TECHNOLOGIES

CONTACT NAME(S) & TITLE(S)
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AFFILIATION(S)
Mosaic Materials
University of California, Berkeley (intellectual property has been licensed from UCB)
Cyclotron Road Alumni
Lawrence Berkeley National Lab (active user proposal)

PROJECT TITLE
Reducing Costs and Environmental Impact of Energy and Materials Generation through Gas Separation Technologies

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INTELLECTUAL PROPERTY STATUS, PATENT OR TECH TRANSFER NUMBER
Patents: Sole licensee of materials patents held by UC Berkeley.

PROJECT/COMPANY STATUS
Company or LLC formed, SBIR and/or STTR grant(s), Other DOE funding, Cyclotron Road participant, Founder(s) plus >2 full-time equivalent employees

TIME TO MARKET – 1 - 3 Years

C2M OBJECTIVES
Insights into which markets Mosaic should focus resources on for our first product. Where is there significant, growing market opportunity? Where are the barriers to entry and adoption lowest? Some of our materials are further along in development than others; it will be extremely valuable to have an independent analysis, rather than continue to focus primarily on those products which are furthest along. We’re specifically looking for in-depth opportunity analyses of 2-3 promising markets.

TECHNOLOGY
The advanced porous solids Mosaic Materials has developed, known as metal-organic frameworks (MOFs), have the potential to improve the efficacy, efficiency, and cost of some of the world’s largest and most widely-practiced separations. Current target applications for Mosaic Materials’ MOFs range from CO2 and toxic gas adsorption to olefin/paraffin separation.

The patented amine-appended MOFs developed by Mosaic Materials for CO2-related applications exhibit switch-like adsorption behavior towards CO2. This unique behavior enables high adsorption capacities and selectivities with mild temperature (< 100°C) or pressure swings to regenerate for the next adsorption cycle. Moreover, the adsorption behavior can be tuned for various process and separation conditions by changing the attached amine. We can make MOFs that are ideal for vastly different applications, from direct CO2 capture from air (400ppm CO2) up to biogas upgrading (35% CO2).
Through a multi-year project with the California Energy Commission, Mosaic Materials designed pilot and theoretical full-scale systems to upgrade biogas (low CH4, high CO2) to pipeline quality renewable natural gas. We demonstrated the incorporation of our MOF-based adsorbents into pellet formulations with high crush strengths while retaining their capacity for CO2. Our current formulation displays negligible decrease in CO2 adsorption over 1000 cycles in lab. A material for olefin/paraffin separations has been similarly scaled through a joint-development agreement with an ethylene producer. Mosaic has collected performance and cycling data on 10+ other materials through a SBIR grant from the US Navy to develop an advanced air scrubbing system for submarines.

TECHNOLOGY READINESS LEVEL
TRL 4 - LAB PROTOTYPE: Component testing in a laboratory environment.

POTENTIAL CUSTOMERS
Market opportunities:
1. CO2-selective materials: natural gas sweetening, life-support systems (such as the enclosed atmosphere of a space vehicle), post-combustion or direct air capture of CO2, industrial CO2 removal (e.g. H2 generation, syngas)
2. Olefin/paraffin separations: acetylene adsorption, ethylene/ethane, propylene/propane etc. – these separations account for significant energy usage in chemical manufacturing (making plastics, etc).
3. Toxic gas adsorption: H2S removal, ammonia removal

Customer pain points addressed:
- For CO2-selective materials:
  o We can provide a cost-effective and environmentally improved alternative to aqueous amine scrubbers, which require large amounts of additional energy, steam, use toxic chemicals, and cannot be scaled once installed.
  o Our materials maintain a high capacity for CO2 and continue to adsorb down to very low concentrations of CO2, e.g. hundreds of ppm. This range is not accessible with current adsorbents.
- For olefin/paraffin separations:
  o Reducing the required separation energy
  o Increasing the selectivity of adsorption (higher purity, smaller equipment possible)
  o Improved recovery of raw materials for recycle back into the process, thus driving more attractive product economics
- In general, we reduce the cost of separations by:
  o Reducing the energy required to regenerate the adsorbent
  o Increasing the selectivity of adsorption (higher purity, smaller equipment possible)

SCALING
We are utilizing a local toll facility to manufacture our MOF-based adsorbents at batch sizes up to 2 kg. At this level, we can produce sufficient material to support a pilot demonstration and provide samples to potential customers/partners. From here, Mosaic may opt to either purchase equipment to manufacture the material internally, or to have it manufactured by a larger contract facility.

The approach to technology scaling and time to reach scale will be highly dependent on the market(s) selected. In markets where Mosaic may be able to offer a system
optimized around our proprietary adsorbents, we aim to license the design or technology. To enable efficient scaling, we may develop modular systems that can be stacked in parallel (to increase throughput) or in series (to maximize adsorbent efficiency).

**ADVANTAGES**

In addition to superior separation performance (high selectivity, high capacity over a range of conditions), Mosaic’s materials have the following advantages over other MOF technologies:
- The “switch-like” adsorption behavior is unique among CO2 adsorbents
- They can be manufactured without toxic solvents
- The formed materials are generally stable in air
- Manufacture at the kg+ scale has already been demonstrated

Mosaic’s MOFs are used in a similar manner to current solid adsorbents (temperature swing or pressure-swing adsorption processes), which the gas processing industry is very familiar with, while delivering better material performance characteristics.

**BARRIERS**

Adsorbent lifetime: For some applications, we must demonstrate that our materials have a lifetime of at least 3-5 years in service. This lead time can be mitigated by pursuing single use applications, or by completing extended testing well in advance of commercialization. One example of where Mosaic Materials is addressing this risk is through on-going material stability tests with raw biogas at a wastewater treatment plant, and with in-house long-term cycle testing to begin this spring.

Manufacturing risk: The cost of the material may not come down with further increases in scale (100+ kg) as drastically as anticipated, or there may be supply chain complications. Mosaic is assessing the trade-offs of manufacturing the organic precursor ligand in-house to address part of this risk as the company grows. The company is actively investigating ways to reduce the cost to produce material.

**FEEDBACK**

The company has received investment funding from Evok Innovations and Baruch Future Ventures, cleantech funds focused on the development and commercialization of solutions to pressing environmental and economic challenges.

The company has also received funding from the California Energy Commission for a multi-year project to develop a concept CO2 removal unit for producing pipeline quality renewable natural gas from biogas. Our progress on the scale-up, process design, and techno-economic portions of the project was well received at our most recent Technical Advisory Committee meeting. Previously, Mosaic Materials received a Phase 1 SBIR grant from the DoD (Navy) to develop and commercialize MOFs for CO2 capture from breathing air in submarine environments. Mosaic Materials has applied for Phase 2 funding; this application is currently under negotiation.

Mosaic Materials also has sponsored development agreements with multiple industry partners, some of which have been extended to include early-stage commercialization terms.

The Cyclotron Road community, our investors and our board members continue to be supportive of our team and our accomplishments to date. Mosaic Materials has a track record of successfully completing projects and continuing to de-risk our technology.
TIME TO MARKET BACKGROUND
For bulk material sales, we anticipate needing to scale our manufacturing by an additional 2 orders of magnitude for lead markets, as well as optimizing our methods for forming the material into structured solids (e.g. pellets, tablets, extrudates). We expect to accomplish this in the next 1-3 years. We are currently able to manufacture selected MOF-based adsorbents at the 1-5 kg scale. In addition, we know we are able to secure funded joint development projects with industry partners, as we have these types of agreements in place already.

The sale or license of fully engineered and guaranteed separation systems/process technology would require significant additional process development, engineering work, and de-risking in the field. The best estimate of time-to-market for such systems is at least 3-5 years.

SUPPORTING MATERIALS
First attachment: One-page overview of the company.