OPUS 12 – RECYCLING CARBON DIOXIDE BACK INTO FUELS AND CHEMICALS

APPLICANTS & AFFILIATIONS

Nicholas Flanders, Opus 12, Cyclotron Road, Lawrence Berkeley National Lab, Stanford University, SLAC

PARTNERS - Shell

INTELLECTUAL PROPERTY STATUS, PATENT OR TECH TRANSFER NUMBER(S)
Currently filing patents - all IP is owned by company

TIME TO MARKET - Within the next 12 months

C2M OBJECTIVES

Opus 12 has developed the world’s most powerful CO₂ conversion device. At scale, our reactor has the CO₂ conversion power of 37,000 trees – or 64 football fields of dense forest – packed into the volume of a suitcase. We have created a platform technology that can be used to recycle CO₂ back into over 16 different products.

Our reactor design is radically scalable, so our technology can meet a number of different customer needs. We would like help in going deep on a few of the markets that we have identified as high-margin first applications, e.g., modular onsite gas production, or providing feedstocks to synthetic biology. We expect to learn surprising customer insights in how our technology could provide significant value in these niche markets. What is the total market size of our first markets?

Secondly, electricity is the primary cost driver in our process. Hence, a key piece of our go-to-market strategy will be to identify areas with high CO₂ emissions and low-cost electricity. We could use help in developing a heat map of opportunities in the U.S. and beyond.

TECHNOLOGY

What if the emissions of the world’s largest industries never reached the air? What if those emissions were instead transformed into valuable assets for the global economy? At Opus 12, we are developing a bolt-on device that recycles CO₂ back into fuels and chemicals (Figure 1).
Using only water and electricity as inputs, we have demonstrated the electrochemical reduction of carbon dioxide (ECO2R) to 16 different products, including ethylene, ethanol, and syngas, which can be upgraded to carbon-neutral diesel, jet fuel, or gasoline.

Originally founded at Stanford in 2015, we are now operating out of LBNL through the Cyclotron Road program. We have developed a breakthrough reactor design for ECO2R, and have built and tested a high-performance prototype that is ready for scale-up. We have exceeded the best-known published performance for CO2 reduction by a factor of 5X.

The main contributor to Opus 12’s record results is our novel integration of CO2-reducing catalysts into an industrially-established reactor architecture, which allows us to take advantage of its high performance, proven track record, and low capital cost.

In addition to recognition from Shell GameChanger and Cyclotron Road, we are also the 2015 winners of the DOE Transformational Idea Award and the Fortune Cool Companies competition. We were accepted into the StartX startup accelerator and completed the I-Corps program. Kendra (CTO) is one of the Levo 100 Millennial Innovators for 2015, and Nicholas (CEO) was among Forbes 30 Under 30 for Energy in 2016.

CUSTOMERS

Who would consume our CO2-derived ethylene, syngas, ethanol, and other products? Companies seeking to reduce their carbon footprint from plastics and fuels without sacrificing the economics of conventionally-made products. We can create these low-carbon products from any CO2 source, but existing fuel producers (oil refineries, corn ethanol plants, and natural gas fields) represent an attractive initial source of CO2. In the U.S. alone, they emit 100Mt of pure CO2, leaving $40Bn of potential value on the table and exposing themselves to future regulatory risk. In addition, they already have supply chains in place for the products we make. Exxon, Shell, Valero and major ethanol manufacturers have validated our value proposition.

Shell has expressed a strategic interest in our ability to make carbon-neutral syngas from CO2, and has provided grant funding for an initial feasibility study.
They have described our achievements as “groundbreaking”.

We have conducted over 150 customer interviews across the oil & gas, chemicals, gas delivery, utilities, ethanol and basic materials sectors.

In the short term, we have identified a high-margin niche application of our technology: small-scale modular CO production that replaces CO delivered in canisters. Current small-scale consumers of CO pay a huge danger premium to have it transported and stored, so our electrolyzer could provide a significant savings in cost and improvements in convenience. We could meet this customer need with our pilot device, which we aim to begin producing in 12 months.

Even longer term, ECO2R could provide critical services on an extraterrestrial colony. The atmosphere of Mars is 95% CO2, so an ECO2R device could convert the Martian atmosphere and ice into plastic building blocks for a habitation, or into methane for refueling rockets (Figure 2).

![Figure 2](image)

**Figure 2.** The atmosphere of Mars is 95% CO₂, so an ECO2R device could convert the Martian atmosphere and ice into plastic building blocks for a habitation, or into methane for refueling rockets.

**SCALING**

A key advantage of electrochemical technology is that it scales linearly, which means that we can produce modular units that can be interconnected to achieve the desired output. At commercial scale, we will use the same size modules as existing PEM water electrolyzers: 250kW, about the size of a checked luggage. A 1MW system would include four modules, and would process 5-10 tons of CO2 per day.

Our manufacturing partner has provided us with specifications for the cell we need to send them in order for them to integrate into a full electrolyzer stack. Our pilot device will be a 5kW unit, which could produce about 15 kg of CO per day for our initial niche application. The next milestone would be to increase the capacity of this stack to 250kW.
ADVANTAGES

ECO2R is at the nexus of the energy and chemicals systems of the future, replacing fossil feedstocks with renewable electrons, air, and water. Further, ECO2R could become a game-changing link between renewable power and synthetic biology (e.g., synthetic animal proteins or high-value resins) by providing a non-land use energy source (syngas) instead of sugars for future microbes to metabolize.

The paradigm-shifting benefits of ECO2R are not limited to the developed world: In the same way that mobile phones have leapfrogged landlines and microgrids have leapfrogged centralized generation in many developing economies, ECO2R could reshape the future development of industrial infrastructure by enabling distributed, low-capex production of carbon-neutral chemicals and fuels.

We have designed our modular reactor to integrate directly with intermittent renewable electricity. In this way, we could produce carbon-neutral fuels or carbon-negative plastics. Our reactor design is radically scalable, so we can serve small-scale customers that competing technologies cannot reach.

BARRIERS

Since we are producing products that are already widely available, there is relatively lower market risk, as long as we can offer competitive economics; the fact that our products have a much lower CO2 footprint is an added incentive. Hence, the main risk is technical: can we achieve a conversion efficiency that will allow us to generate cost-competitive products? We are addressing this risk in two ways: first, by gathering the best team in the world for electrochemical CO2 reduction, and second, by pursuing high-margin niche applications that we have identified through over 200 customer interviews, which will allow us to get to market faster.

The second core barrier to commercialization was alluded to in a previous answer: identifying enough markets with attractive electricity prices. We will mitigate this risk by doing a region-by-region analysis of both electricity prices and the barriers to accessing the lowest rates.

FEEDBACK

In general, we have received significant interest from existing oil and gas players, e.g., Shell, Exxon, Chevron, Total, and Valero. Players like Shell and Total have begun to make significant investments in renewable electricity assets, so the concept of turning electrons into chemicals that they already produce from fossil feedstocks is attractive. Early in 2015, we saw significant interest around our ethylene product, but given recent price collapses, this interest has decreased. The most attention has been paid to our renewable syngas product - whether as an input to Fischer Tropsch (this is what Shell is funding us to do), as an input to a
polymerization process (Covestro, formerly Bayer Chemical, is very interested), or as salable CO (Air Liquide and Praxair are interested in modular CO production).

For our onsite CO niche application, distributors like Air Liquide and Praxair have validated the value proposition and the potentially significant margins. We have only just begun customer discovery with end-users. This could be a valuable part of the C2M assistance.

**ACADEMIC/JOB TITLE(S)** - Co-Founder & CEO, Opus 12

**STATUS**

Company or LLC formed, Other DOE funding, NSF funding, I-Corps participant, Cyclotron Road participant, FLOW, CTO or other business plan competition(s), Bench scale prototype(s), Significant lab performance data, Founder(s) plus 1-2 full-time equivalent employees

**TIME TO MARKET BACKGROUND**

We are beginning commercial partnerships for pilot development with Proton Onsite over the next couple of months, and Shell is beginning the feasibility study with us during that time period as well.

Over the next 12 months, we aim to develop our first pilot (5kW) reactor, which is actually the right size for onsite CO production in some of the niche applications we have identified.
OPUS 12

RECYCLING CO₂

Kendra Kuhl  Nicholas Flanders  Etosha Cave
Solution: recycling CO₂ back into fuels and chemicals

CO₂ → H₂O → Electricity → OPUS¹² → Fuels & Chemicals

Prepared for C2M – 2
Impact: Up to 1/3 of global CO$_2$ emissions

100% = 32.9 billion tons CO$_2$

36% Addressable emissions

64%
Electrochemical reduction of CO$_2$

carbon dioxide + water

16 compounds
Our CO₂ conversion performance: like 64 football fields of dense forest…

…37,000 trees… in a suitcase-sized reactor
Team: uniquely positioned to bring this product to market

**Team:** 20 years of ECO2R research, previous startups

- Nicholas Flanders, CEO
  MBA/MS E-IPER, Stanford
  COO/CFO Levo, McKinsey Cleantech

- Dr. Kendra Kuhl, CTO
  PhD in Chemistry, Stanford
  Post doc, SLAC

- Dr. Etosha Cave, CSO
  PhD in Mechanical Eng, Stanford

**Advisors: leaders in their fields**

- Catalyst engineering: Prof. Thomas Jaramillo, Stanford
- Reactor design: Prof. John Newman, UC Berkeley
- Polymer development: Prof. Nate Lynd, University of Texas
- Plant design, process engineering: Mark Warner, Warner Advisors

Prepared for C2M – 7
We can address the pain points of diverse customer segments.

Need to reduce large, concentrated CO₂ emissions

Need to find uses for off-peak generation

Need the products we can make

Chemical plants
Waste treatment
Ethanol
Oil refineries
Submarines
Ethanol plants
Chemical plants
Waste treatment
Consumers
Natural gas processing

Utilities
Renewable power manufacturers
Aluminum
Waste treatment
Submarines
Ethanol w/ cogen
Municipalities (waste + fleets)

Consumer goods (packaging)
Gas delivery
Semiconductors
Pharmaceuticals
Airlines

Prepared for C2M – 6
Our team has been recognized for our innovation and vision

Competition winner:

We have secured key development partnerships and grant funding to achieve rapid, capital-light results

Contact: Nicholas@opus-12.com