OPUS 12

REVERSE COMBUSTION

KENDRA KUHL, CTO

Prepared for DOE 18f Webinar

Team: Uniquely positioned to bring this product to market.

NICHOLAS FLANDERS, CEO

MS E-IPER, Stanford
Work Experience: COO/CFO Levo
McKinsey CleanTech practice

DR. KENDRA KUHL, CTO

PhD in Chemistry, Stanford
Post doc, SLAC
Research: Transition metal catalyzed CO_2 electroreduction, reactor design

DR. ETOSHA CAVE, CSO

PhD in Mechanical Eng, Stanford
Research: Modified gold catalysts for CO_2 electroreduction, reactor design

FOUNDING TEAM

SICHAO MA, SENIOR CHEMIST

PhD in Chemistry, University of Illinois Urbana-Champaign
Research: ECO2R ethylene catalysis, reactor design

GEORGE LEONARD, SENIOR CHEMIST

BS Chemistry, Carnegie Mellon
Work Experience: CO_2 catalysis, reactor design - Liquid Light

DANIEL DIAZ, CHEMIST

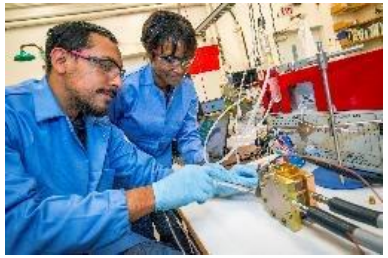
MS Material Science, University of Michigan
Work Experience: Silicium

ANNIE ZENG, ENGINEER

BS Mechanical Engineering
Olin College of Engineering
Work Experience: Alteros

Traction: Scaling up our record-setting prototype at Lawrence Berkeley National Lab





OPUS 12

WE HAVE SECURED KEY DEVELOPMENT PARTNERSHIPS AND GRANT FUNDING TO ACHIEVE RAPID, CAPITAL-LIGHT RESULTS

SBIR FUNDING FROM THREE AGENCIES:

U.S. DEPARTMENT OF ENERGY

NASA

NSF

KEY COMMERCIAL PARTNERSHIPS:

Shell GameChanger

PROTON THE LEADER IN ON SITE GAS GENERATION.

HIGHLY SELECTIVE INCUBATORS:

cyclotronroad

StartX

TomKatCenter FOR SUSTAINABLE ENERGY STANFORD UNIVERSITY

echoing green

IP STRATEGY: SCHOX, PLC

Our solution: a platform technology that recycles CO_2 back into chemicals and fuels

1

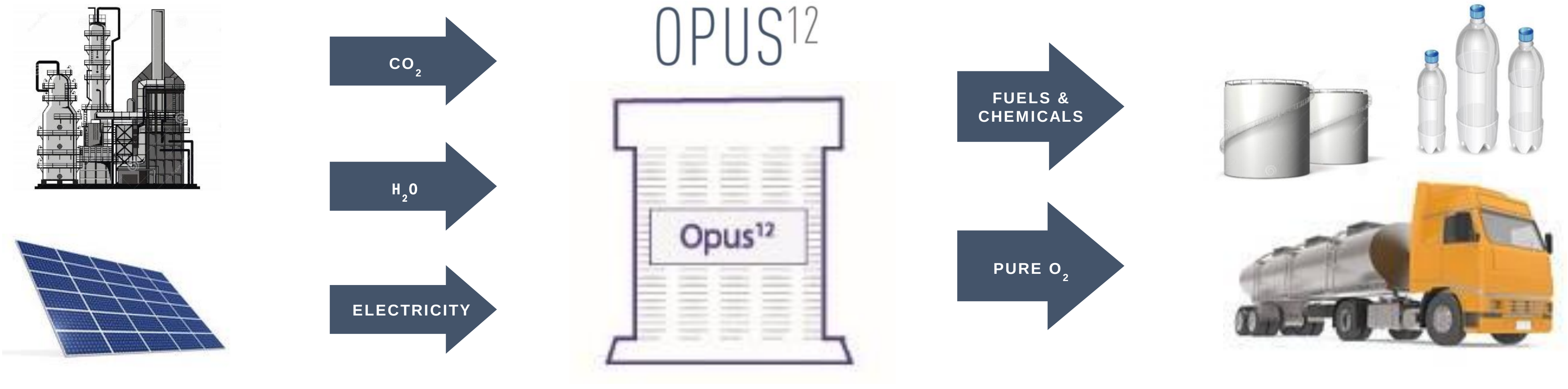
INPUTS: CO_2, WATER, ELECTRICITY

2

ELECTROCHEMICAL REDUCTION OF CO_2

3

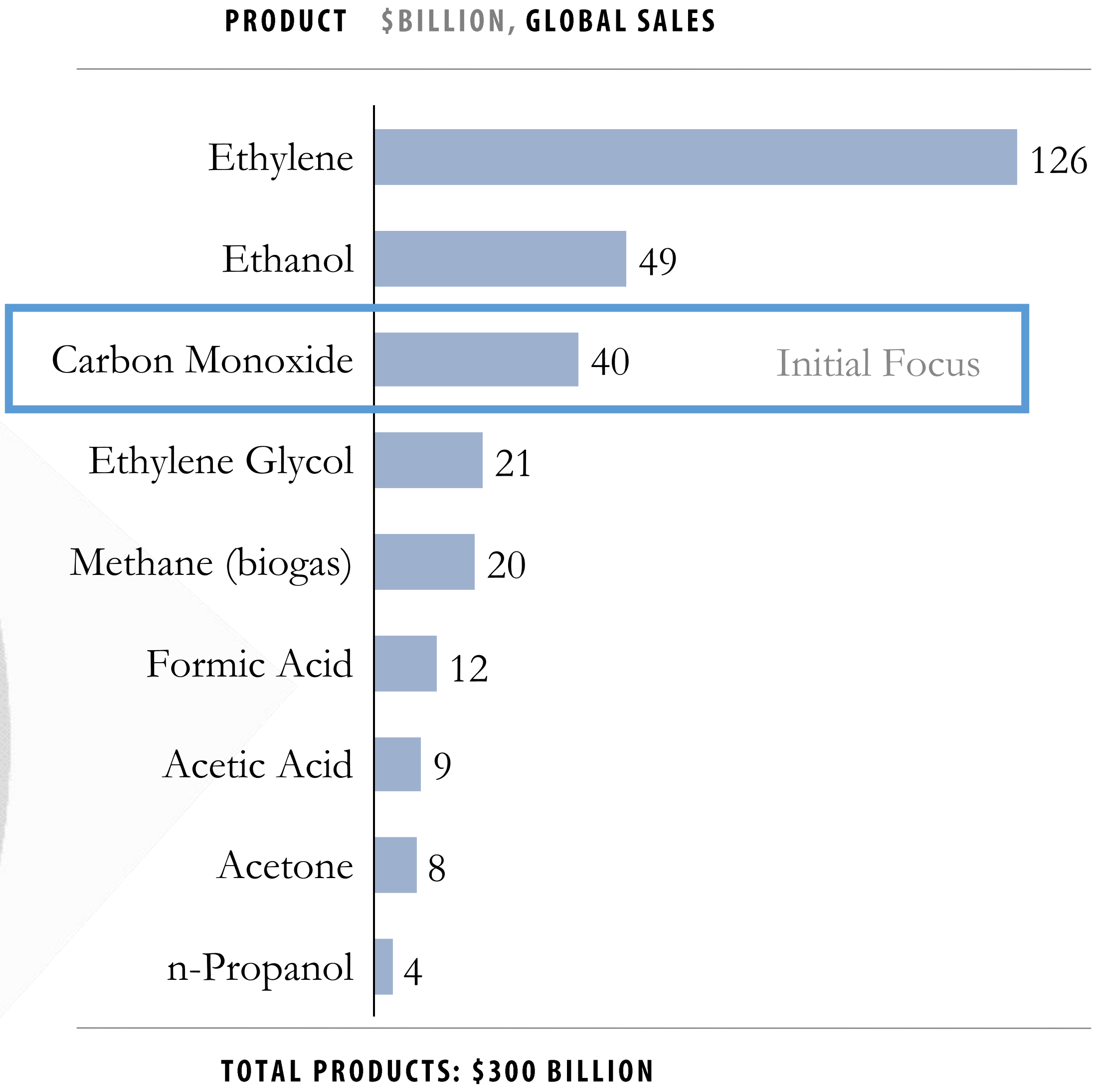
OUTPUTS: PRODUCTS THAT DROP INTO EXISTING SUPPLY CHAINS



Electrochemical CO_2 conversion (ECO2R): a $300 billion global market

The global market for our technology is huge and diversified: nearly $300 billion and growing at over 4% per year.

Our team has demonstrated the electrochemical conversion of CO2 into 16 different products; the top nine by market value are illustrated here



250KW INCREMENT

1MW COMMERCIAL PEM H_2 SYSTEM

Opus 12’s drop-in component converts PEM H_2 electrolyzers into CO_2 electrolyzers, allowing us to take advantage of decades of advances in PEM technology.

We are the first group in the world to integrate CO_2-converting catalysts into a PEM electrolyzer.

Image: Proton OnSite M Series 1 MW PEM water electrolyzer

By integrating into a PEM electrolyzer, we capture all of the benefits of an existing industrial reactor design, while significantly reducing scale-up risk

Advantages of PEM reactor architecture

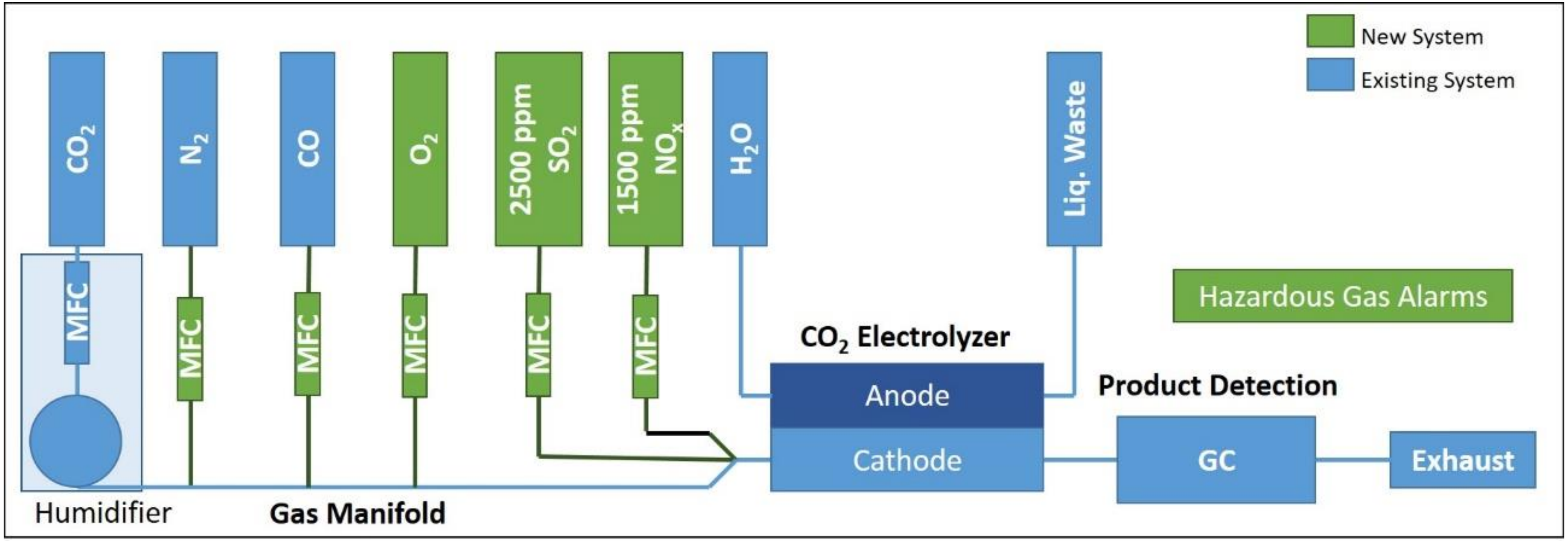
- **Commercial readiness** – deployed around the world for decades
- **Fast ramp times** – enables use of intermittent low-cost electricity (modern systems can integrate directly with a wind turbine)
- **Low capex**, thanks to years of commercial development and mild operating conditions
- **Modularity and scalability** –allows for integration with CO_2 sources of diverse volumes
- **High current density**, leading to a small footprint
- **Operational simplicity** – no need for specialized operators on site

We are developing a flue gas simulation system, which will enable us to test our system with realistic feedstock compositions

U.S. DEPARTMENT OF ENERGY

TOPIC FOR SBIR PHASE 1
($150K, STARTS JULY 2016)

Simulated flue gas delivery system and electrolyzer testing setup



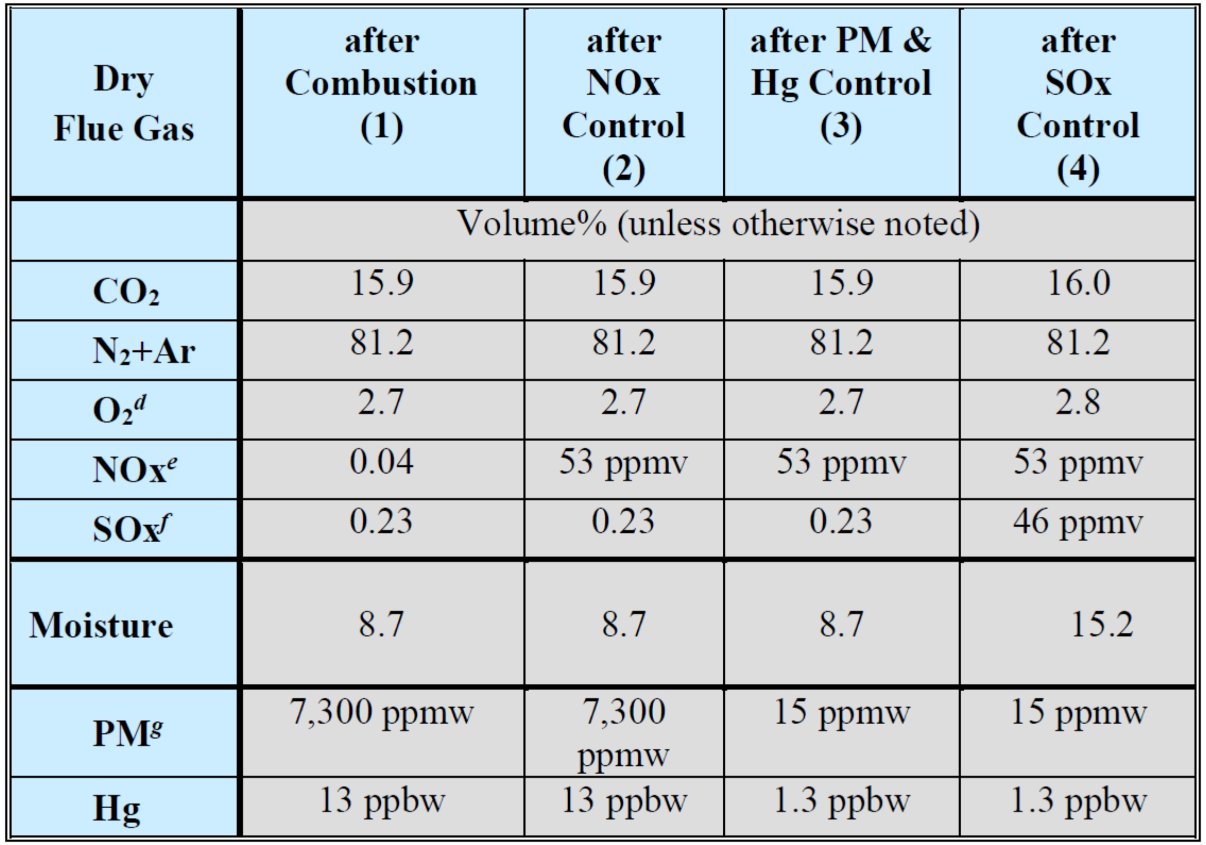
Entire setup contained inside large vented enclosure.

Gas mixtures examined

Original Ranges Proposes

Gas tested	**Simulated flue gas**		**Individual gas testing**	
	Coal power	CCGT	Concentration Range	Balance
CO_2	12	7	5-100%	N_2
CO	50	300	500 ppm-5%	CO_2
O_2	4	5	1-10%	CO_2
SO_2	400	n/a	25-500 ppm	CO_2
NO_x	400	70	25-500 ppm	CO_2

Typical Flue Gas Mix
Shared by Dave Lang

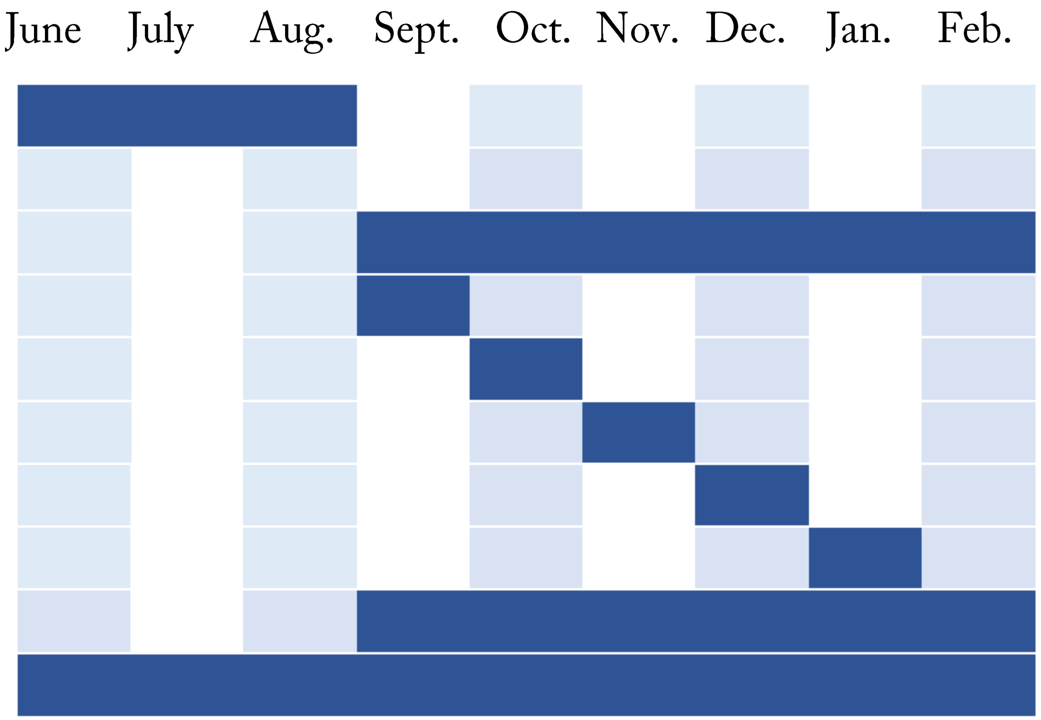


Dry Flue Gas	**after Combustion (1)**	**after NOx Control (2)**	**after PM & Hg Control (3)**	**after SOx Control (4)**
	Volume% (unless otherwise noted)			
CO_2	15.9	15.9	15.9	16.0
N_2+Ar	81.2	81.2	81.2	81.2
O_2^d	2.7	2.7	2.7	2.8
NOx^e	0.04	53 ppmv	53 ppmv	53 ppmv
SOx^f	0.23	0.23	0.23	46 ppmv
Moisture	8.7	8.7	8.7	15.2
PM^g	7,300 ppmw	7,300 ppmw	15 ppmw	15 ppmw
Hg	13 ppbw	13 ppbw	1.3 ppbw	1.3 ppbw

Project Timeline

IV. Performance Schedule

IV.1 Workplan Overview



Project Plan Tasks	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
Equipment setup and calibration	■	■	■						
Performance testing – various gas inputs:									
• Simulated flue gas mixtures				■	■	■	■	■	■
• Carbon dioxide				■					
• Carbon monoxide					■				
• Oxygen						■			
• Sulfur dioxide							■		
• Nitrogen oxides								■	
In situ catalyst reactivation testing				■	■	■	■	■	■
System modeling	■	■	■	■	■	■	■	■	■

Table 4.1 Gantt chart listing tasks and timeline of completion for the course of the 9-month project (38 weeks).

Project Goals

- Preliminary determination of CO_2 purity needed to maintain reactor performance
- Assess what purification technologies are needed to achieve the necessary purity
- Develop approximate cost model for cost of getting CO_2 from a coal or natural gas power plant