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ENERGY ALTERNATIVES

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About Mantra Energy Alternatives Ltd.

- Technology development company
- Owner of **ERC Technology**
- Exclusive licenser of **MRFC Technology**
- 11 employees, including 8 full-time R&D staff (3 Ph.D.s)
- Research facilities in Vancouver, BC, Canada

Mantra Energy's Team

Management

- Larry Kristof - *Founder and CEO* - 20+ years in entrepreneurship and management
- Glenn Parker - *Director* - 25+ years in investment and capital management
- Patrick Dodd - *VP, Corporate Development* - Master's degree in Clean Energy Engineering
- Sona Kazemi, Ph.D. – *Chief Technology Officer* - Ph.D. electrochemical engineer
- Piotr Forysinski, Ph.D. - *Product Design Engineer* - Ph.D. physical chemist
- Tirdad Nickchi, Ph.D. - *Senior Electrochemical Engineer* - Ph.D. electrochemist
- Randy Gue - *Industry Specialist* - 30+ years in process engineering at Lafarge Canada

Advisory

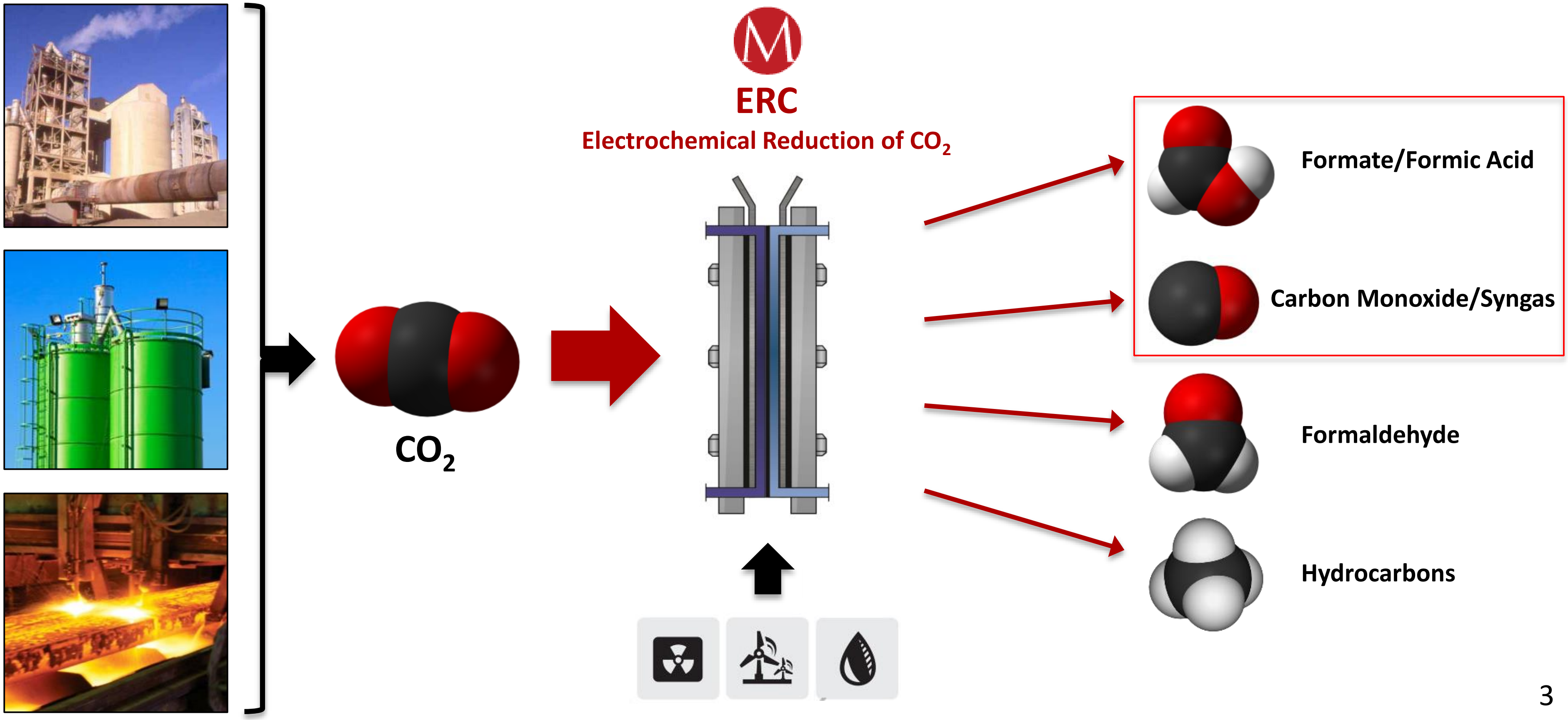
- Professor Emeritus Colin Oloman - 50+ years in electrochemical engineering & design
- Professor Plamen Atanassov - Leading expert in electrocatalysis and fuel cells
- Dr. Alexey Serov – Assistant Professor in electrocatalysis and catalyst synthesis
- Norman Chow - President of Kemetco Research, history in technology commercialization

Partners & Collaborations

- GE
- LAFARGE
- NORAM
- BC RESEARCH
- UBC
- INRS Université d'avant-garde
- UNM
- University of Toronto
- Canada
- Mitacs

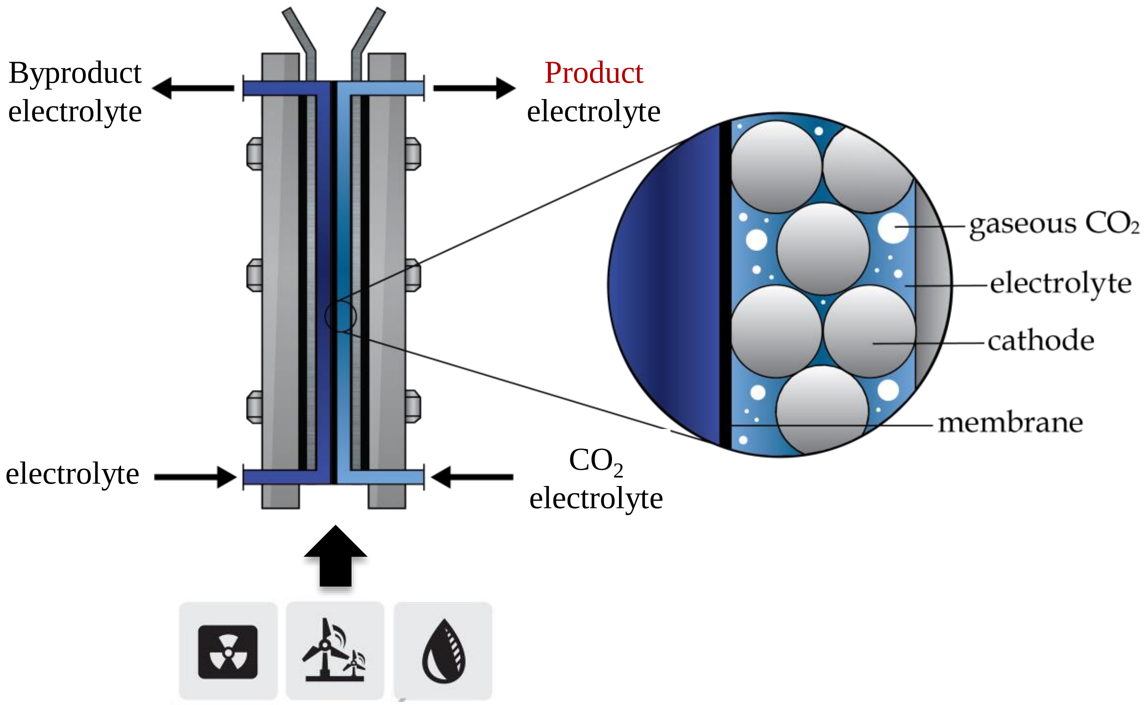
Electrochemical Reduction of CO_2 (ERC)

- CO_2 can be electrochemically reduced to a variety of chemicals, with high selectivity through catalysis
- To date, Mantra has focused on formate/formic acid and carbon monoxide/syngas



Electrochemical Reduction of CO_2 (ERC)

- CO_2 and electrolyte are introduced co-currently to the cathode, where the reduction reactions occur
- The CO_2 reduction is selective to a specific product based on the cathode catalyst material employed
- A complementary oxidation reaction occurs at the anode, generating a byproduct that also has value



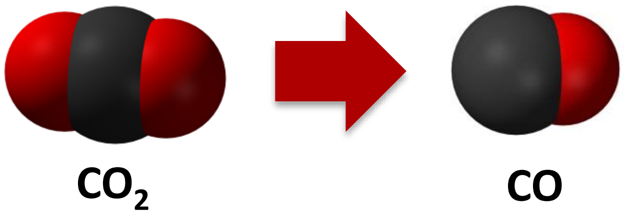
Potential Cathode Reactions

$CO_2 + 2H^+ + 2e^- \rightarrow H_2C_2O_4$
$CO_2 + 2H^+ + 2e^- \rightarrow HCOOH$
$CO_2 + 2H^+ + 2e^- \rightarrow CO + H_2O$
$CO_2 + 2H^+ + 2e^- \rightarrow HCHO + H_2O$
$CO_2 + 2H^+ + 2e^- \rightarrow CH_3OH + H_2O$
$CO_2 + 2H^+ + 2e^- \rightarrow CH_4 + 2H_2O$
… among others

Potential Anode Reactions

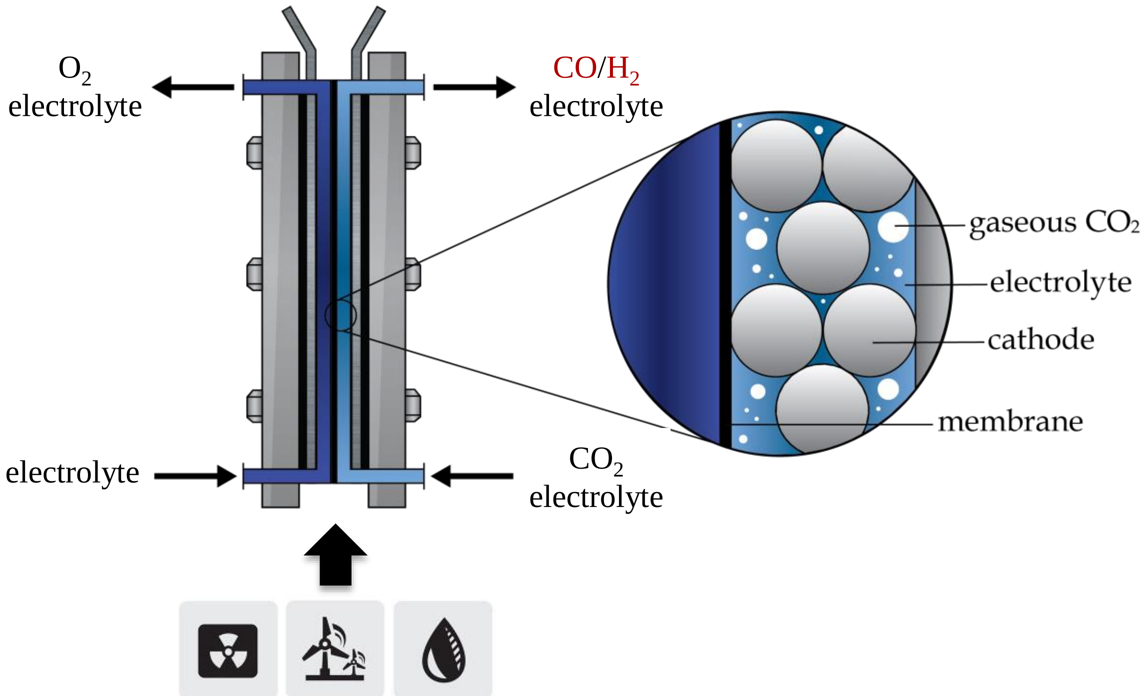
$2H_2O \rightarrow O_2 + 2H^+ + 2e^-$
$2HCl \rightarrow Cl_2 + 2H^+ + 2e^-$
$2HBr \rightarrow Br_2 + 2H^+ + 2e^-$
$C_6H_6 + 2H_2O \rightarrow C_6H_4O_2 + 6H^+ + 6e^-$
$H_2O \rightarrow OH\cdot + e^- + H^+$
… among others

Electrochemical Reduction of CO_2 to Syngas



Electrochemical Reduction of CO_2 to Syngas

- CO_2 is reduced to CO and H_2O to H_2, creating a mixture of $CO/H_2/CO_2$ (syngas)
- The syngas ratio (H_2:CO) is tunable based on parameters such as current density and electrode design
- Because the process is "on/off", it can take advantage of excess renewable electricity when available



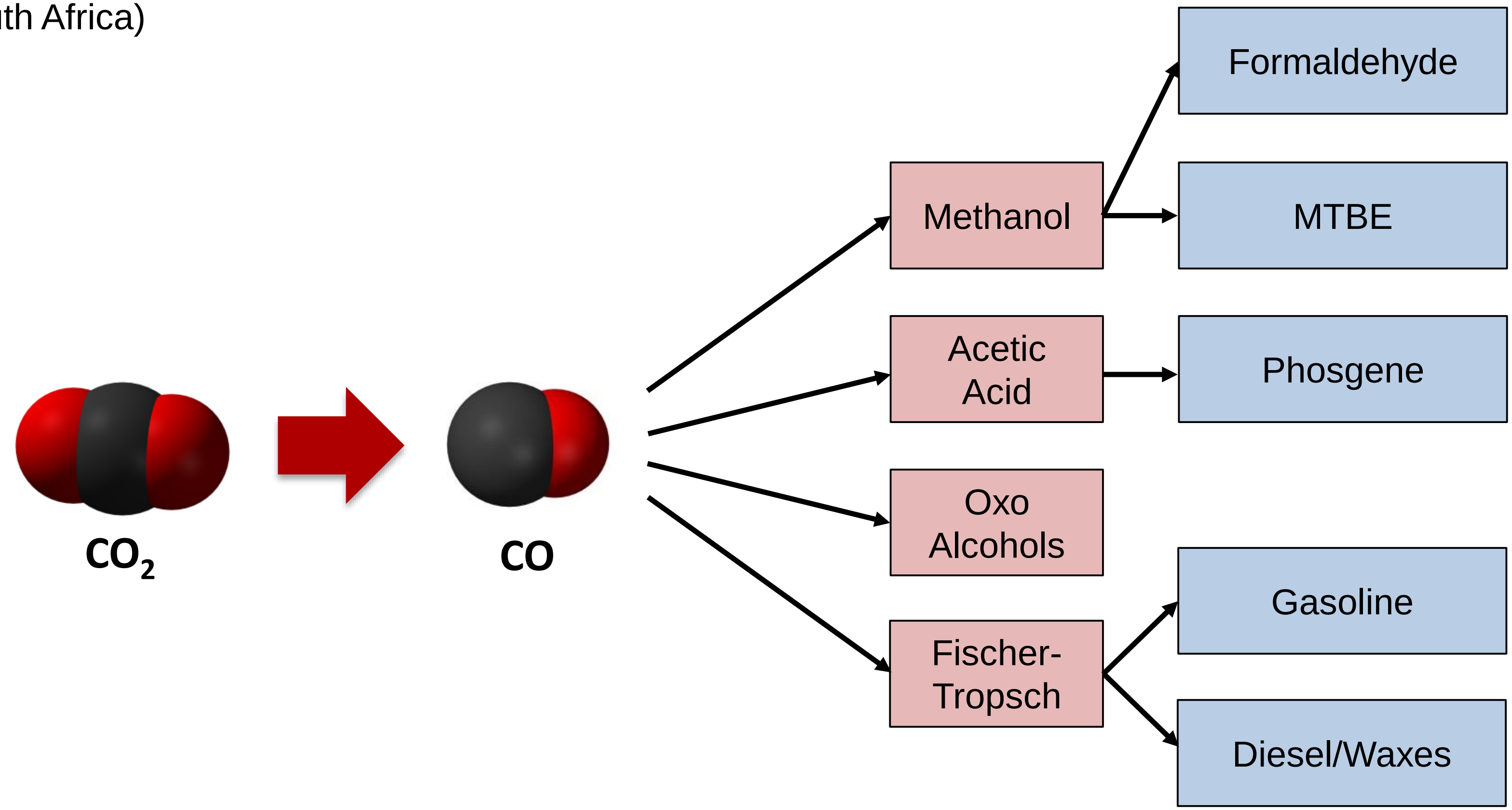
Net Reactions

$$CO_2 \rightarrow CO + \tfrac{1}{2}O_2$$
$$H_2O \rightarrow H_2 + \tfrac{1}{2}O_2$$

$$CO_2 + H_2O \rightarrow CO + H_2 + O_2$$

Syngas as Feedstock for Chemicals and Fuels

- Syngas is an important “building block” for the chemicals industry all across the world
- Methanol production alone demands >50 million tonnes CO per year globally, and it is rapidly growing
- Through Fischer-Tropsch synthesis, hydrocarbon mixtures can be produced (used to produce gasoline in South Africa)



Advantages of CO_2 electro-reduction to Syngas

- CO_2 becomes a carbonaceous feedstock for the chemicals and fuels industry
- Process can serve as a sink for excess renewable electricity from intermittent sources
- With CO and H_2 produced in the same reactor, the syngas product can be used directly
- The only consumables are CO_2, water (or potentially wastewater), and electricity
- Wastewater (e.g. produced water) could be treated by this process
- Electrochemical system can be made modular and easily transportable
- Process does not require heat and can operate at ambient pressure and temperature
- Syngas ratio (H_2:CO) is “tunable”, making the process flexible for a range of end products

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Opportunities for CO_2-to-Syngas in Alberta

1. Stand-alone process for converting CO_2 into syngas and subsequently products such as methanol, ethanol, naphtha, diesel, gasoline, jet fuel, etc.

2. Addition to existing syngas utilizing process

3. Utilizing wasted energy; e.g. natural gas flaring, process heat, etc.

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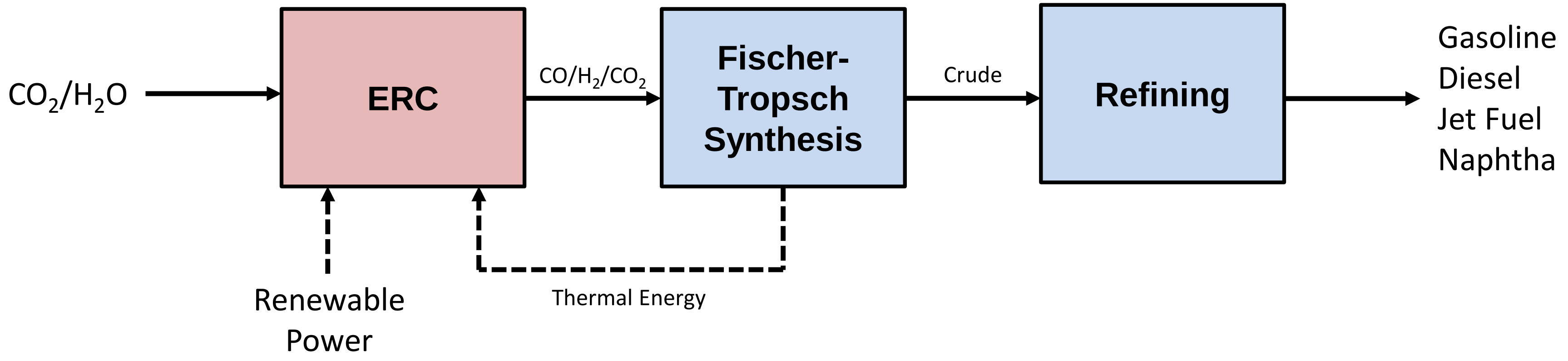
Opportunities for CO_2-to-Syngas in Alberta

1. **Stand-alone process for converting CO_2 into syngas and subsequently products such as methanol, ethanol, naphtha, diesel, gasoline, jet fuel, etc.**

Example: Stand-alone ERC combined with a GTL process; no net consumption of chemicals other than CO_2 and H_2O; no by-products



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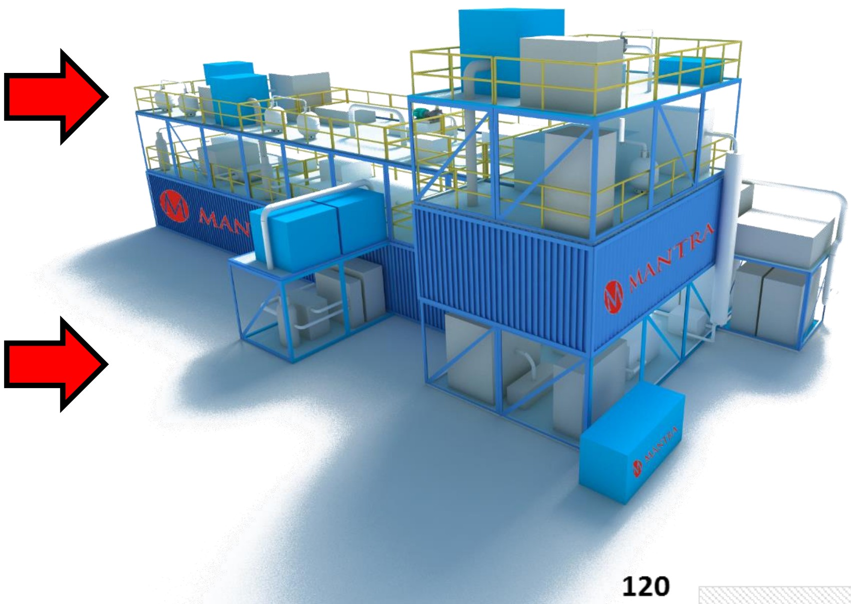
Economical Considerations of the CO_2-to-Diesel Process
(41 tpd CO_2 to 100 bpd Diesel)

CO_2

Pessimistic: $70/tonne
Base: $45/tonne
Optimistic: $0/tonne

Electricity

Pessimistic: $56/MWh
Base: $28/MWh
Optimistic: $2/MWh

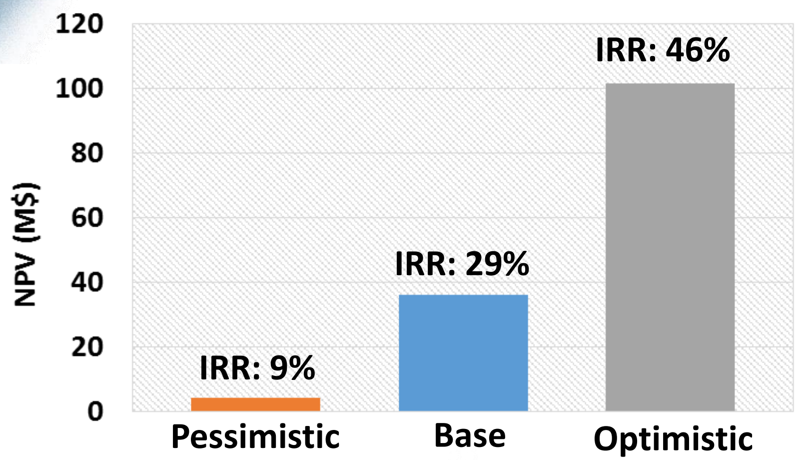


Green diesel

$2,300/tonne

Assumptions:
Plant lifetime: 25 years
Discount rate: 6%
Capacity factor: 0.9
No carbon tax or offsets

	Pessimistic	Base	Optimistic
Capex (M$)	13.3	13.3	20.5
Opex (k$/day)	26.1	18.4	1.1
Payback period (years)	9.8	3.4	2.1
Production cost ($/tonne)	2,260	1,660	460



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Economical Considerations of the CO_2-to-Naphtha Process

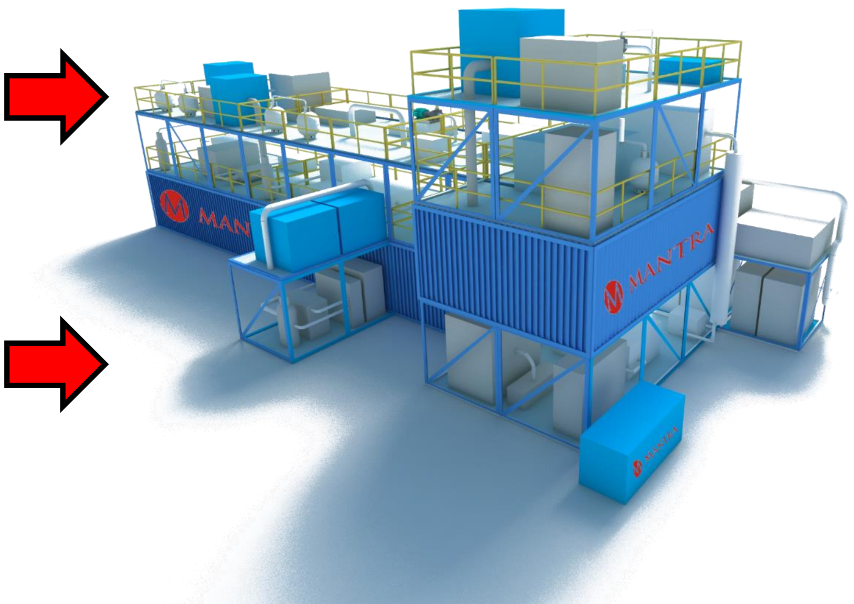
(41 tpd CO_2 to 120 bpd Naphtha)

CO_2

Pessimistic:	$70/tonne
Base:	$45/tonne
Optimistic:	$0/tonne

Electricity

Pessimistic:	$56/MWh
Base:	$28/MWh
Optimistic:	$2/MWh



Naphtha

$950/tonne

<u>Assumptions:</u>

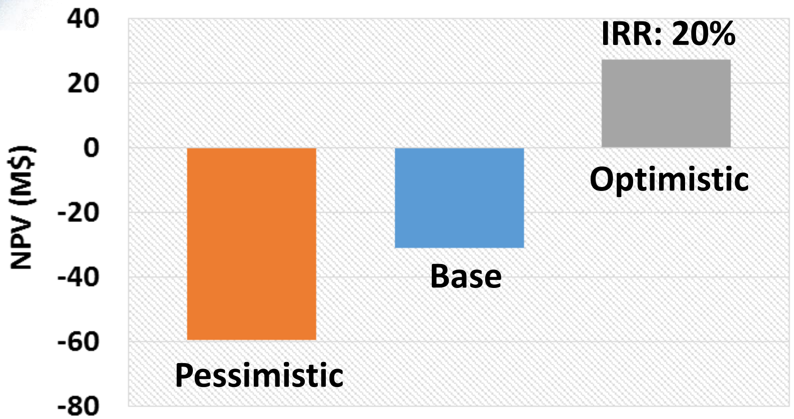
Plant lifetime: 25 years

Discount rate: 6%

Capacity factor: 0.9

No carbon tax or offsets

	Pessimistic	Base	Optimistic
Capex (M$)	14.3	14.3	21.6
Opex (k$/day)	26.1	18.4	1.1
Payback period (years)	-	-	4.9
Production cost ($/tonne)	2,200	1,650	470



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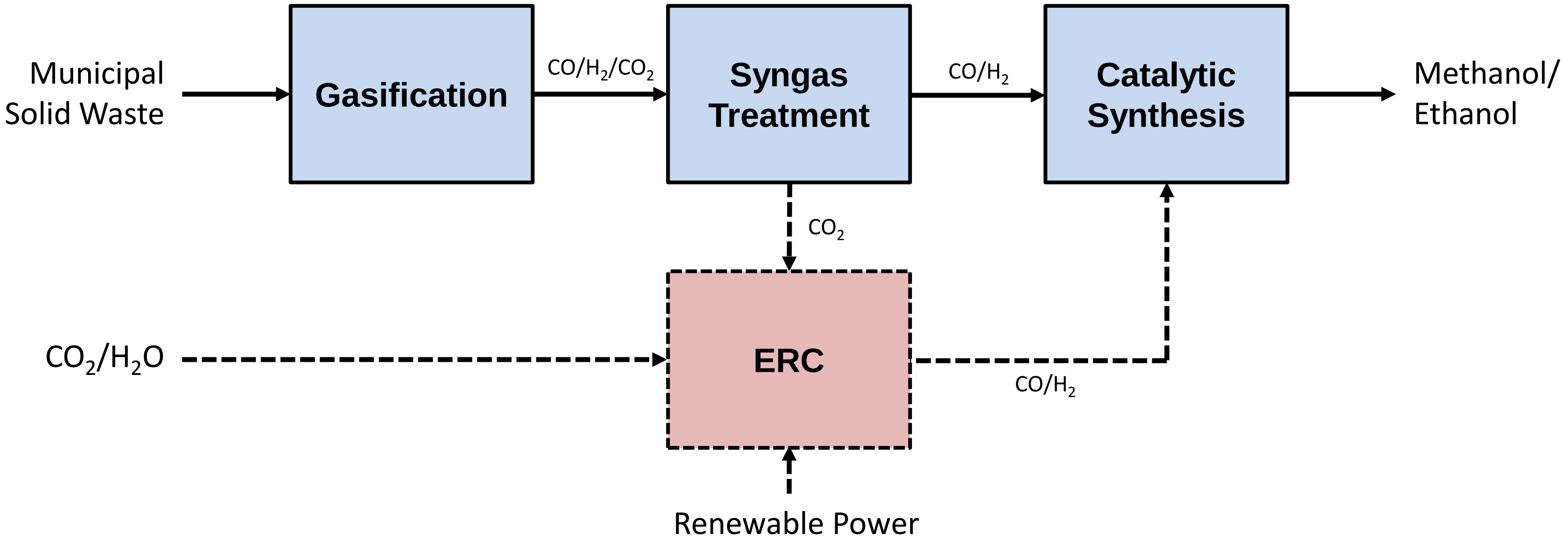
Opportunities for CO_2-to-Syngas in Alberta

2. Addition to existing syngas utilizing process

Example: Addition to Enerkem MSW-to-ethanol plant

- When renewable power is available or in excess, CO_2 can be converted to syngas to supplement that produced in the gasification process
- This provides a sink for excess energy, a means of recycling CO_2 emissions and an increased use of the existing infrastructure



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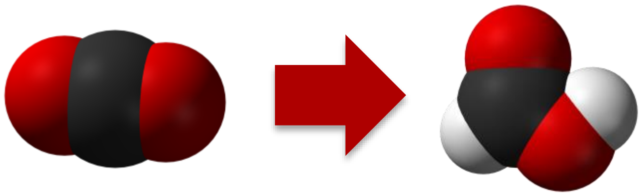
Opportunities for CO_2-to-Syngas in Alberta

3. **Waste energy recovery to power the ERC process**

Example: Natural gas flaring

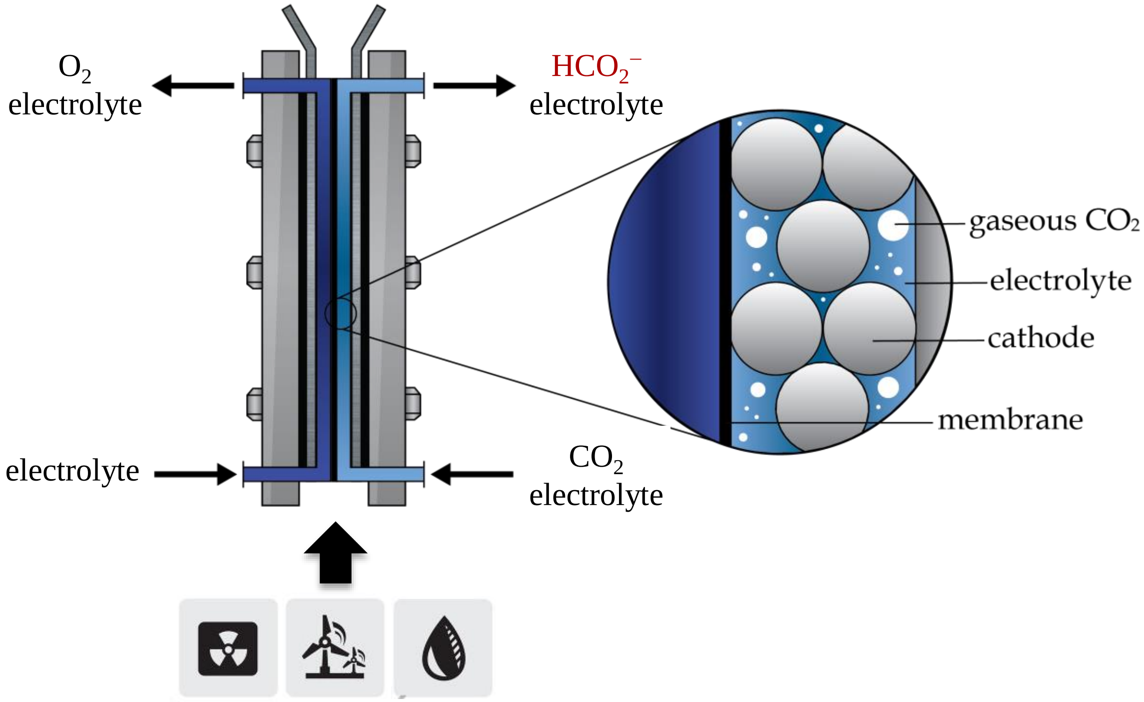
- Approximately 140 billion m^3 of natural gas is burnt at the flares annually, causing more than 300 million tons of CO_2 to be emitted to the atmosphere (Elvidge et al. 2009)
- This is equivalent to 750 billion kWh of electricity
- In Alberta, about 7% of the natural gas at upstream oil and heavy oil sites was flared or vented in 2008; this was equivalent to 2 million tons of CO_2 (Johnson and Coderre, 2010)
- The “Zero Routine Flaring by 2030” initiative, introduced by the World Bank, brings together governments, oil companies, and development institutions who recognize the flaring situation described above is unsustainable from a resource management and environmental perspective, and who agree to cooperate to eliminate routine flaring no later than 2030

Electrochemical Reduction of CO_2 to Formate/Formic Acid



Electrochemical Reduction of CO_2 to Formate/Formic Acid

- Process can operate in alkaline or acidic media, thereby producing either formate or formic acid
- In alkaline media, bicarbonate/carbonate salts are produced as a byproduct; these can be sold or recycled back into the process



Net Reactions

Alkaline Conditions

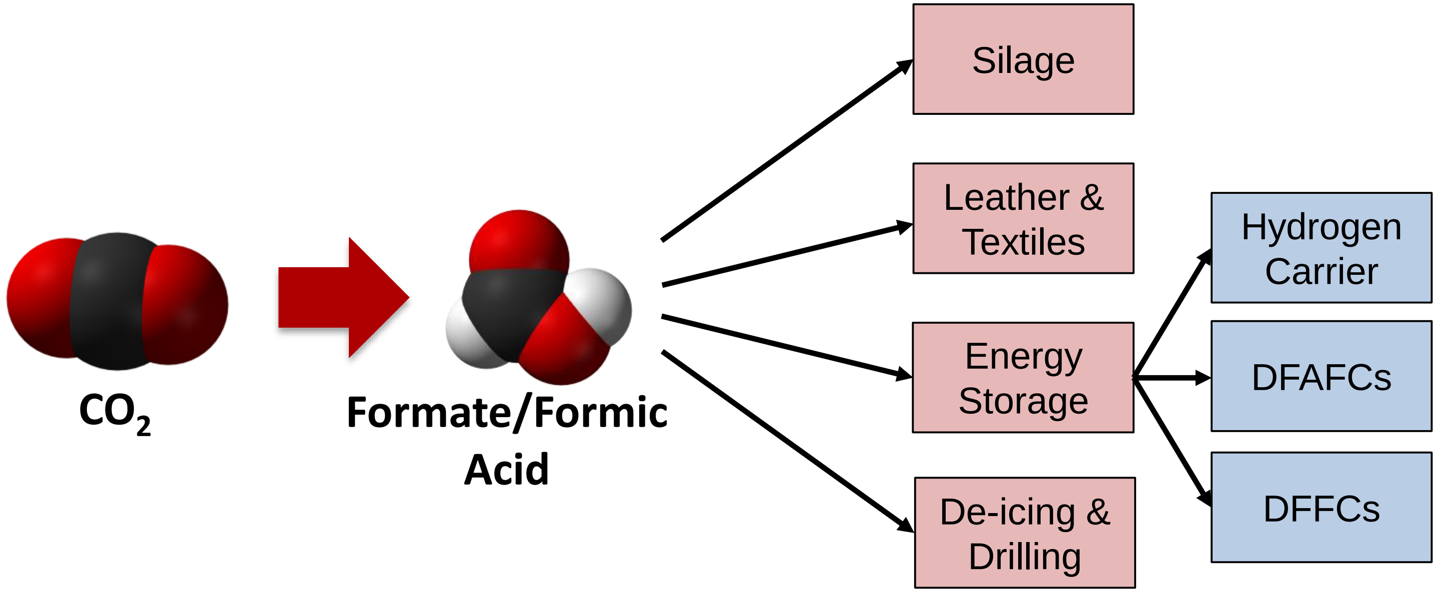
$2CO_2 + 2NaOH \rightarrow NaHCO_2 + NaHCO_3 + ½O_2$

Acidic Conditions

$CO_2 + H_2O \rightarrow H_2CO_2 + ½O_2$

Electrochemical Reduction of CO_2 to Formate/Formic Acid

- Formic acid is a naturally occurring, environmentally benign organic acid used in agriculture and manufacturing
- Formate salts (Na^+, K^+, Cs^+) are used as environmentally benign de-icing agents for airports, as heat transfer fluids, and in oil well drilling and finishing
- Formate and formic acid are excellent energy carriers; formic acid is also an effective carrier of hydrogen for fuel cells



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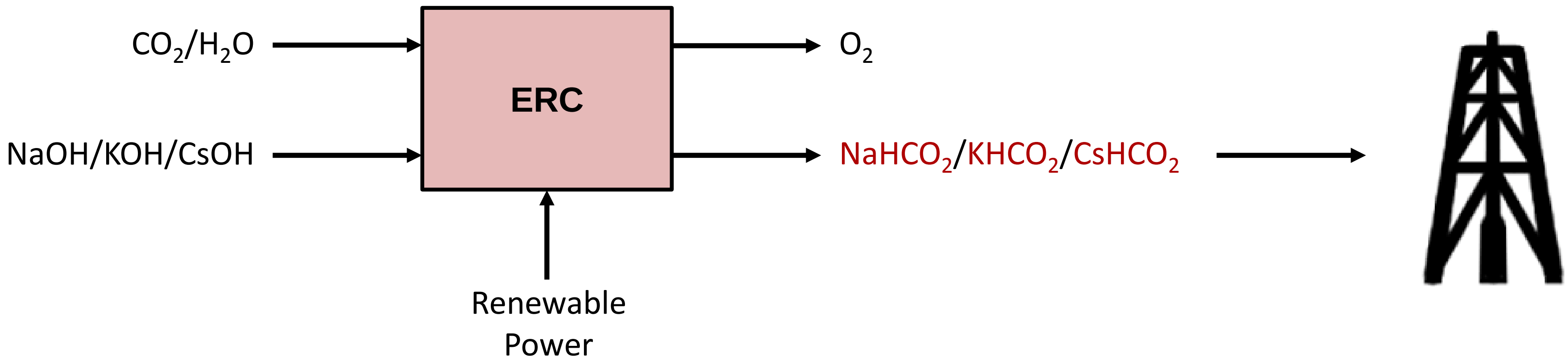
Opportunities for CO_2-to-Formic Acid/Formate Salts in Alberta

1. Production of formate brines for oil well completion
2. Production of formic acid/formate brines for clean power production in fuel cells

Opportunities for CO_2-to-Formic Acid/Formate Salts in Alberta

1. Production of formate brines for oil well completion

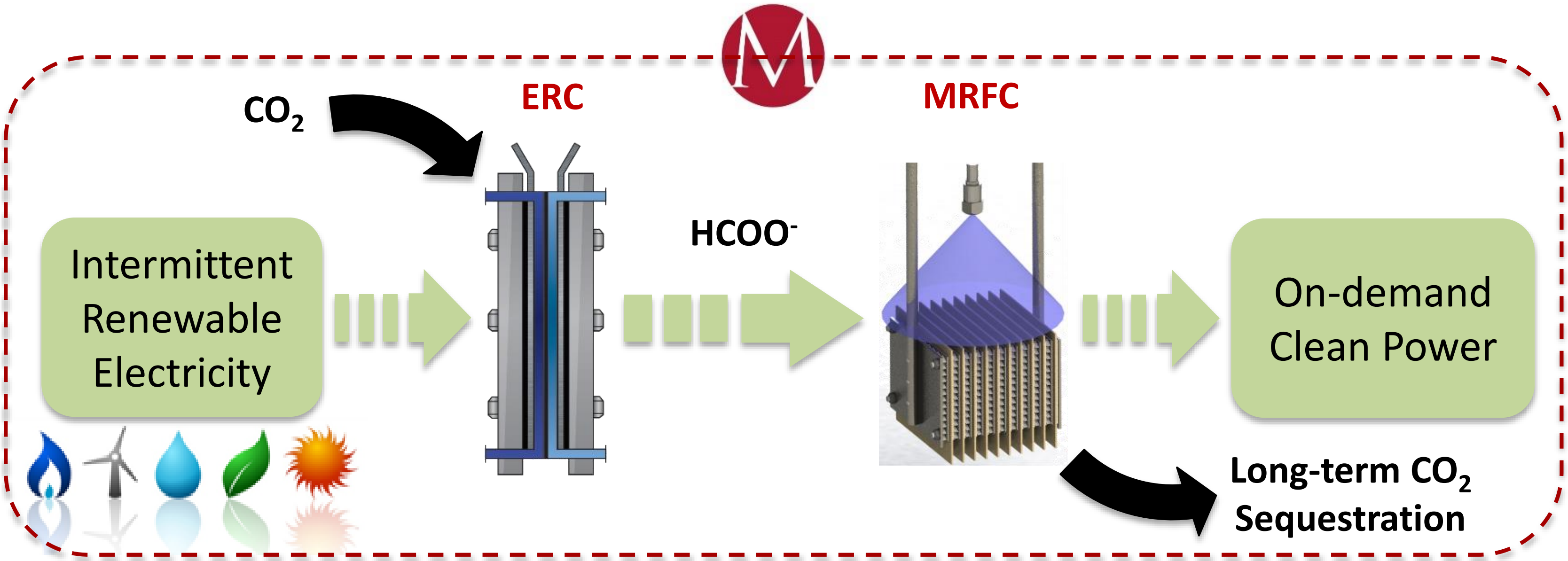
- Formate brines are excellent oil well drilling and completion fluids (Na^+, K^+, Cs^+)
- Advantages include: being solids free; good lubricity; shale stabilization; less corrosive than conventional fluids; and being non-toxic and readily biodegradable
- Formate brines have been used in Western Canada drilling, including the hard, abrasive shales of Montney



Opportunities for CO_2-to-Formic Acid/Formate Salts in Alberta

2. Production of formate brines for clean power production in fuel cells

- As renewable energy technologies are integrated into the grid, storage is increasingly critical
- Converting CO_2 into formate can provide a scalable energy storage solution
- Mantra is developing a novel low-cost fuel cell that can be integrated with ERC to complete this energy storage system



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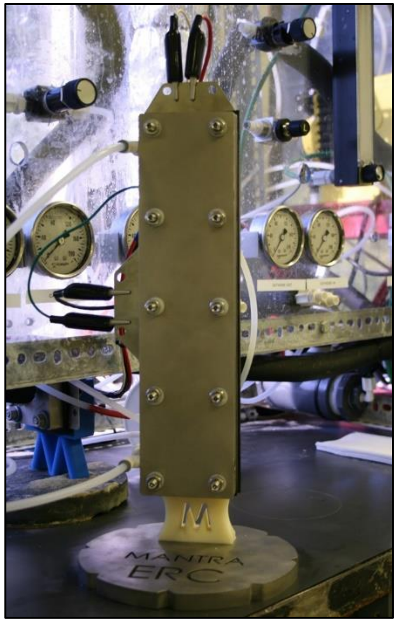
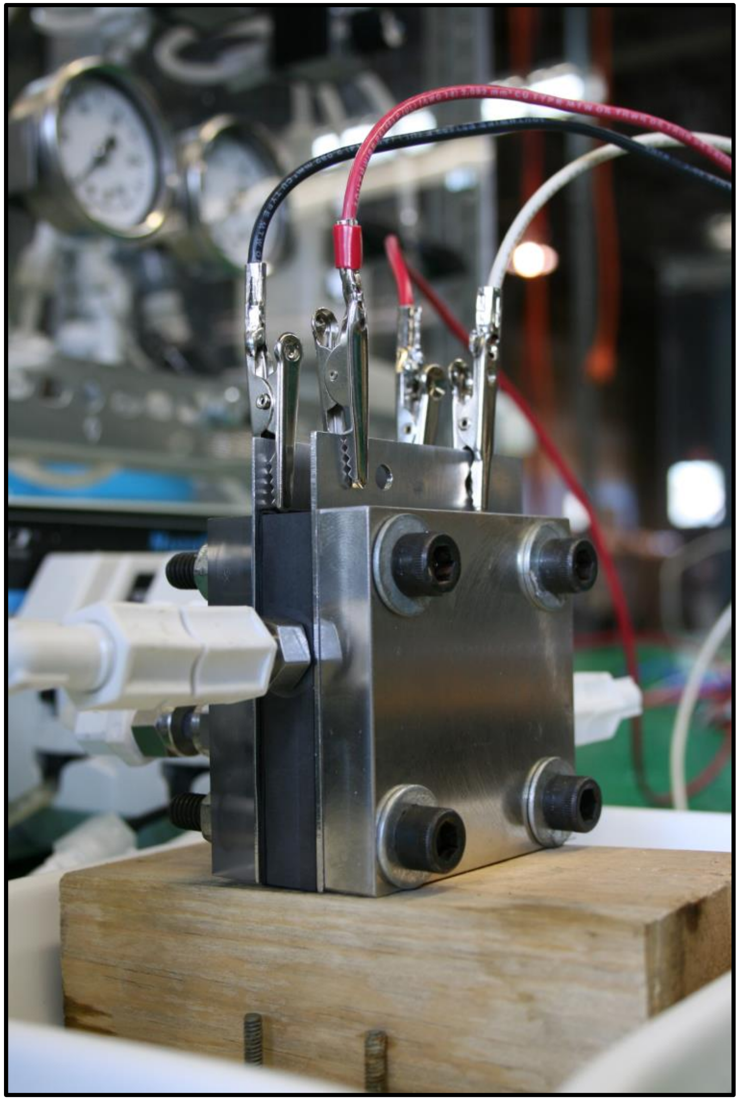
ERC



MRFC

Mantra Spark

Bench-Scale ERC Reactors



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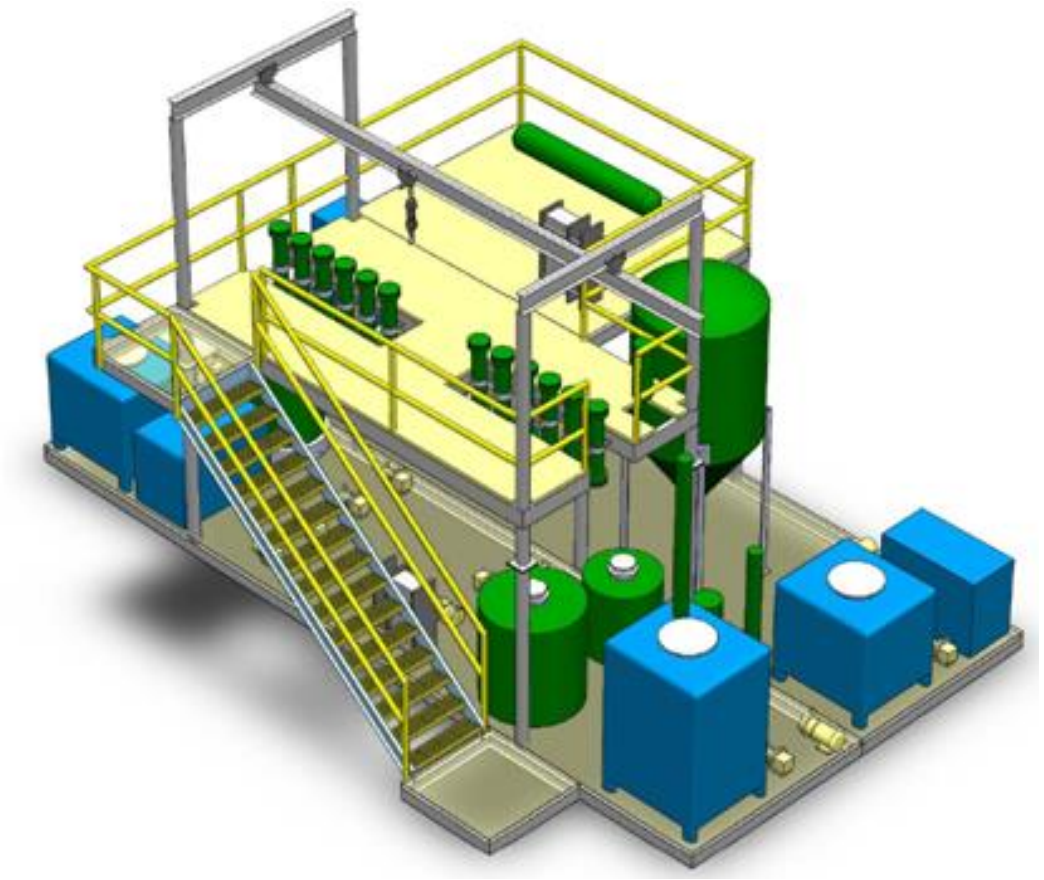
Planned Scale-up and Demonstration



Demonstration I LAFARGE

- Lafarge cement plant in Richmond
- 100 kg/day CO_2 to formate/formic

Demonstration II Ayinger

- Ayinger brewery in Bavaria
- 100 kg/day CO_2 to other products

NORAM
BC RESEARCH

Intellectual Properties

Intellectual Property Status

	US	UK	EU	Canada	Australia	China	India
ERC PATENT	Pending		Pending	✓	✓	✓	✓
MRFC PATENT	✓	✓		✓			

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Mantra is developing effective, affordable solutions for some of the world's biggest challenges.