About Mantra Energy Alternatives Ltd.

- Technology development company
- Owner of ERC Technology
- Exclusive licensor 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

- Lafarge
- NORAM
- BC Research
- UBC
- INRS
- UNM
- University of Toronto
- Canada
- Mitacs
Electrochemical Reduction of CO\textsubscript{2} (ERC)

- CO\textsubscript{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 CO₂ (ERC)

- CO₂ and electrolyte are introduced co-currently to the cathode, where the reduction reactions occur
- The CO₂ 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**

\[
\begin{align*}
\text{CO}_2 + 2\text{H}^+ + 2\text{e}^- & \rightarrow \text{H}_2\text{C}_2\text{O}_4 \\
\text{CO}_2 + 2\text{H}^+ + 2\text{e}^- & \rightarrow \text{HCOOH} \\
\text{CO}_2 + 2\text{H}^+ + 2\text{e}^- & \rightarrow \text{CO} + \text{H}_2\text{O} \\
\text{CO}_2 + 2\text{H}^+ + 2\text{e}^- & \rightarrow \text{HCHO} + \text{H}_2\text{O} \\
\text{CO}_2 + 2\text{H}^+ + 2\text{e}^- & \rightarrow \text{CH}_3\text{OH} + \text{H}_2\text{O} \\
\text{CO}_2 + 2\text{H}^+ + 2\text{e}^- & \rightarrow \text{CH}_4 + 2\text{H}_2\text{O} \\
\end{align*}
\]

... among others

**Potential Anode Reactions**

\[
\begin{align*}
2\text{H}_2\text{O} & \rightarrow \text{O}_2 + 2\text{H}^+ + 2\text{e}^- \\
2\text{HCl} & \rightarrow \text{Cl}_2 + 2\text{H}^+ + 2\text{e}^- \\
2\text{HBr} & \rightarrow \text{Br}_2 + 2\text{H}^+ + 2\text{e}^- \\
\text{C}_6\text{H}_6 + 2\text{H}_2\text{O} & \rightarrow \text{C}_6\text{H}_5\text{O}_2 + 6\text{H}^+ + 6\text{e}^- \\
\text{H}_2\text{O} & \rightarrow 0\text{H}^- + e^- + \text{H}^+ \\
\end{align*}
\]

... among others
Electrochemical Reduction of CO$_2$ to Syngas
Electrochemical Reduction of CO₂ to Syngas

- CO₂ is reduced to CO and H₂O to H₂, creating a mixture of CO/H₂/CO₂ (syngas)
- The syngas ratio (H₂: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

\[
\begin{align*}
\text{CO}_2 & \rightarrow \text{CO} + \frac{1}{2}\text{O}_2 \\
\text{H}_2\text{O} & \rightarrow \text{H}_2 + \frac{1}{2}\text{O}_2 \\
\text{CO}_2 + \text{H}_2\text{O} & \rightarrow \text{CO} + \text{H}_2 + \text{O}_2
\end{align*}
\]
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)

![Diagram showing syngas conversion to various products]

- Formaldehyde
- Methanol
- MTBE
- Acetic Acid
- Phosgene
- Oxo Alcohols
- Gasoline
- Diesel/Waxes
- Fischer-Tropsch
Advantages of CO₂ electro-reduction to Syngas

• CO₂ 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 H₂ produced in the same reactor, the syngas product can be used directly

• The only consumables are CO₂, 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 (H₂:CO) is “tunable”, making the process flexible for a range of end products
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.
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$_2$O; no by-products
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

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<th>Pessimistic</th>
<th>Base</th>
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<td>Payback period (years)</td>
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<td>Production cost ($/tonne)</td>
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<td>1,660</td>
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IRR: 9%
IRR: 29%
IRR: 46%
Economical Considerations of the CO₂-to-Naphtha Process
(41 tpd CO₂ to 120 bpd Naphtha)

**CO₂**
- Pessimistic: $70/tonne
- Base: $45/tonne
- Optimistic: $0/tonne

**Electricity**
- Pessimistic: $56/MWh
- Base: $28/MWh
- Optimistic: $2/MWh

**Naphtha**
- $950/tonne

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

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<th>Base</th>
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<td>Production cost ($/tonne)</td>
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**IRR:** 20%
Opportunities for CO$_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
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 CO₂ to Formate/Formic Acid
Electrochemical Reduction of CO₂ 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**

\[ 2\text{CO}_2 + 2\text{NaOH} \rightarrow \text{NaHCO}_2 + \text{NaHCO}_3 + \frac{1}{2}\text{O}_2 \]

**Acidic Conditions**

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_2 + \frac{1}{2}\text{O}_2 \]
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.

![Diagram showing the reduction of CO\(_2\) to formate/formic acid](image)
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
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.
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Bench-Scale ERC Reactors
Planned Scale-up and Demonstration

Demonstration I
- Lafarge cement plant in Richmond
- 100 kg/day CO₂ to formate/formic

Demonstration II
- Ayinger brewery in Bavaria
- 100 kg/day CO₂ to other products
# Intellectual Properties

## Intellectual Property Status

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