Ekona’s
Tri-Generation Pyrolysis (TGP) Solution for Blue Hydrogen Production
December 2019
Ekona Power Inc.

Developing a novel *pyrolysis* platform for H2 production

• **Clean** - 90% fewer GHG emissions than incumbent SMRs
• **Low-cost** - Cost parity or better with incumbent SMRs
• **Scalable** - Suitable for large-scale, centralized industrial applications

We gratefully acknowledge the financial support of the Province of British Columbia’s Innovative Clean Energy (ICE) Fund, the NRC Industrial Research Assistance Program (IRAP) and the Canadian Gas Association (NGIF).
Global H2 Markets

- Petroleum Recovery & Refining
- Ammonia Production
- Methanol Production
- Metal Production and Fabrication
- Electronics
- Food Industry
- Other

Electrolysis – 4%

GHG Emissions
- 673 Mt-CO2e/year
- ~ 1.3% of global GHG’s

H2 Production Cost
- SMR: $1.20/kg-H2
- SMR + CCS: $2.00/kg-H2

Market Size
- Canada: 4 Mt-H2/year
- NA: 15 Mt-H2/year
- Global: 65 Mt-H2/year

10% H2 (vol.) is currently feasible with existing NG pipelines and appliances

Downstream GHG Emission Reduction:
- 3.6%

GHG Emissions (downstream)
- 6,600 Mt-CO2e/year
- ~ 13% of global GHGs

Target Energy Supply Cost
- NG + $50/t CO2 levy = $7/GJ
- ~ $0.85/kg-H2

Market Size (10% H2 vol.)
- Canada: 1.3 Mt-H2/year
- NA: 7.6 Mt-H2/year
- Global: 36 Mt-H2/year
Technology Analysis

Breakthrough Requirements

- **Industrial H2 Production**: Continuous, large-scale
- **Cost Target**: $0.85/kg
- **GHG Emissions Reduction Target**: 90%

Breakthrough Drivers

- Abundant, inexpensive and continuous source feedstock
- Minimize CO2 Separation Costs
- Maximize Carbon Value

Projected Clean H2 Production Cost ($/kg-H₂)

Assumptions

- >90% GHG-free
- CCS: $100/tonne-CO₂
- Electricity: $70/MWh
- Bitumen: $20/bbl
- Coal: $20/tonne
- NG: $4/GJ

[Bar chart showing different methods of clean H2 production cost]
Tri-generation Pyrolysis (TGP)

1 GJ of natural gas generates 3.8 kg H2 and 76 kWh electricity
Pulse Methane Pyrolysis (PMP)

- Pulsed injection of thermal & mechanical energy
- Automatic removal of C-buildup due to unsteady flow
- Fast kinetics quenching via unsteady expansion
- Prototype reactor presently being assembled & tested
- PI Partners: Geminus Technologies, U of W, NRC

Direct Carbon Fuel Cell (DCFC)

- Fuel: solid carbon in a MC mediator
- Advantages: high efficiency + pure CO2 byproduct
- Challenges: carbon delivery to anode
- Prototype button cell is presently being assembled & tested
- PI Partners: NRCan-Canmet Energy, NRC
Preliminary Design

PMP Reactor

Capacity: **100 TPD-H₂, 366 TPD-carbon**
- Scalable for industrial applications
- Low cost reactor design
- Low maintenance / no carbon fouling
- Industry-standard balance of plant
- PMP H₂ Production Cost: $10/GJ

DCFC Module

Capacity: **4 MWe (gross)**
- Containerized modules for site installation
- Industrial stack design for low-cost, industrial scale
- Low maintenance / electrolyte bath
- Pure CO₂ byproduct (CCS / CCU)
- TGP H₂ Production Cost: $5/GJ

40 foot skid

Molten Carbonate Bath

Manifolds

Stack 1  Stack 2  Stack 3  Stack 4

40 foot container
H2 Production Cost

**Pulse Methane Pyrolysis (PMP)**

* pyrolysis only w/o carbon sales

- **Pilot (8 TPD): $1.92/kg**
- **Commercial (100 TPD): $1.36/kg**

**Tri-generation Pyrolysis (TGP)**

* includes DCFC for power generation

- **Pilot (8 TPD): $1.35/kg**
- **Commercial (100 TPD): $0.60/kg**

---

<table>
<thead>
<tr>
<th>H2 Production Cost ($/kg-H2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
</tr>
<tr>
<td>1.00</td>
</tr>
<tr>
<td>1.50</td>
</tr>
<tr>
<td>2.00</td>
</tr>
<tr>
<td>2.50</td>
</tr>
</tbody>
</table>

---

<table>
<thead>
<tr>
<th>Carbon Sales Price ($/tonne)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>70</td>
</tr>
<tr>
<td>80</td>
</tr>
<tr>
<td>90</td>
</tr>
</tbody>
</table>

---

<table>
<thead>
<tr>
<th>Electricity Sales Price ($/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>70</td>
</tr>
<tr>
<td>80</td>
</tr>
<tr>
<td>90</td>
</tr>
</tbody>
</table>

---

- SMR - CO2 Levy $0/t
- SMR - CO2 Levy $50/t
- SMR - CO2 Levy $100/t
- Pilot: 8 TPD Pulse Pyrolysis Plant vs. Carbon Price
- Commercial: 100 TPD Pulse Pyrolysis Plant vs. Carbon Price
GHG Emissions

**TGP Process**
- 0.64 t-CO₂/t-H₂
- CO₂ Sequestered: 1,375 TPD
- Electricity: 73 MW
- GHG Offset: -2.3 t-CO₂/t-H₂

**SMR Process**
- 8-10 t-CO₂/t-H₂
- Flue Gas: 810 TPD
- Water: 600,000 L/day
- NG: 18,600 GJ/day
- Tail Gas
- H₂: 100 TPD

**GHG Emissions Offset**
- ~10 kg-CO₂/kg-H₂

**TGP versus SMR**
- 90% GHG reduction
- 100% H₂O reduction

**GHG emissions reductions applied across all markets:**
- Canada: 50 Mt-CO₂/year ~ 7% of Canada’s GHGs
- Global: 1 Gt-CO₂/year ~ 2% of global GHGs

*CAD electricity grid: 130 kgCO₂/MWh*
<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Market and Technical Requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Technology Formulation &amp; Core Technology Testing (TRL3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Proof-of-Concept Development &amp; Testing (TRL4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Pilot-scale Prototype Development &amp; Testing (TRL5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Brass-board System Development &amp; Testing (TRL6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>PMP Customer Field Trials &amp; Evaluation (TRL7-9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>PMP Commercial Rollout</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>DCFC Introduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Customer Requirements Document (CRD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Preliminary Design and Techno-economic Analysis Validated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lab-scale PMP Reactor &amp; DCFC Verified</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pilot-scale PMP Reactors Verified</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BOP Integration Testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>200 kg/day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Roadmap**
Field Testing of pyrolyzer system with lead customers is under development

- **Lab-scale PMP Reactor Testing**
  2019-2020

- **Pilot-scale PMP Reactor Testing**
  2020-2021

- **PMP Field Trial Skid (~200 kg-H2/day)**
  2022-2023
Chris Reid, Chief Executive Officer
151 West Hastings Street
Vancouver, BC, Canada
V6B 1H4
Cell: (604) 761-2798
Email: chris.reid@ekonapower.com

Gary Schubak, Sales and Marketing
151 West Hastings Street
Vancouver, BC, Canada
V6B 1H4
Cell: (604) 908-0830
Email: gary.schubak@ekonapower.com