Biohydrogen from Alberta's Biomass Resources for Bitumen Upgrading

Adetoyese Oyedun, Amit Kumar

NSERC/Cenovus/Alberta Innovates Associate Industrial Research Chair Program in Energy and Environmental Systems Engineering

Department of Mechanical Engineering, University of Alberta, Edmonton, Canada
OUTLINE

- Background
- Overview of hydrogen production
- Biohydrogen pathways
- Comparative economic and environmental metrics
- Key observations
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Research on Energy and Environmental Systems Engineering

Theme Area 1
Integrated Energy-Environmental Modeling

Theme Area 2
Energy Return on Investment (EROI) of Energy Pathways

Theme Area 3
Techno-economic Assessment of Energy Conversion Pathways
Background – Need for Hydrogen

- Upgrading of bitumen to synthetic crude oil (SCO) is highly $\text{H}_2$ intensive.

- Based on projections, oil sands (bitumen) production capacity will increase from 2.4 million barrels/day in 2015 to 3.7 million barrels/day by 2030 (CAPP, 2016).

- About 2.4 – 4.3 kg/bbl bitumen of hydrogen is used during the upgrading of bitumen.

- Hydrogen is needed for hydrotreating and hydrocracking.

- The projected hydrogen requirement for oil sands upgrading is about 4 million tonnes/yr by 2040.
Steam methane reforming (SMR) is the predominant means of H$_2$ production - Demerits include: feedstock volatility, greenhouse gas (GHG) emissions, and the use of a premium fossil fuel, i.e., natural gas.

The energy market is increasingly GHG constrained; there is a growing global consensus that GHG mitigation is a policy imperative.

Reducing SCO related GHG emissions with respect to other light crudes is a prudent measure for market competitiveness.
Systems Approach to Hydrogen Production from Alternative Sources

- Natural Gas
- Wind Energy
- Hydropower
- Underground Coal
- Biomass
- Reforming
- Electrolysis of Water
- Gasification + CCS
- Gasification/Pyrolysis

Hydrogen

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Feedstocks for Biomass-based Hydrogen (Biohydrogen) Production

- Considered biomass feedstocks:
  - **Whole forest** – whole-tree biomass.
  - **Forest residues** – tree tops, branches, needles which are left after the logging operation.
  - **Agricultural residues** – blend of straw from wheat and barley crops.
Biohydrogen Production Pathways: Gasification

- **Biomass gasification of whole-tree-based biomass forest residues and agricultural residues**

  - Biomass harvesting
  - Chipping & drying
  - Gasification
  - Tar cracking

  - $H_2$ compression, storage, & transport
  - Purification of $H_2$
  - Water-gas shift reforming
  - Gas clean up & compression

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Biohydrogen (Gasification)

**BCL Gasifier**
- No air-flow in gasifier
- Atmospheric pressure

**GTI Gasifier**
- Oxygen-flow in gasifier
- High pressure

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Generalized Modelling Methodology

- Energy Resource Characterization
  - Specification of Unit Operations for H₂ Production Pathway
  - Characterization Process Equipment for Unit Operations
  - Determination of Energy/Resource Inputs for Process Equipment

- Techno-Economic Model

- H₂ Cost Metrics
- H₂ Cost Sensitivities

- Cost Estimation Data: Scale Factors, Feedstock Cost, Capital Costs, Labour and Installation Costs, etc.
- Economic Data and Assumptions: Internal Rate of Return (IRR), Inflation, Plant Lifetime etc.

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Biohydrogen (Gasification) Production Cost


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Biohydrogen Production Pathways: Pyrolysis

- **Biomass pyrolysis of whole-tree-based biomass, forest residue, agricultural residue**

**Flowchart:**
- **Biomass harvesting** → **Chipping, grinding, & drying** → **Fast pyrolysis** → **Bio-oil quenching and separation**
  - **Purification of H₂** → **Water-gas shift reforming** → **Bio-oil steam reforming** → **Bio-oil/CH₃OH transportation**

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Biohydrogen (Pyrolysis): Unit Operations

- Biomass pyrolysis
- Feedstock drying
- Feedstock size reduction
- Biomass transportation
- Biomass processing
- Biomass harvesting
- Bio-oil separation
- Bio-oil transportation
- Bio-oil reforming
- Syngas clean up
- Water-gas shift reaction
- Hydrogen purification
- Hydrogen compression
- Methanol
- Pipeline
- Truck
- H₂ for bitumen upgrading
Bio-Hydrogen (Pyrolysis): H₂ Cost


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Transportation cost of Biohydrogen

* For 167 tonnes of $\text{H}_2$/day

Source: Sarkar and Kumar, Trans. of ASABE, 2009, 52(2), 1-12.
Biohydrogen Cost of Production – Different Biomass & Pathways

*Sarkar and Kumar, 2010. All costs in 2016 C$.
Biohydrogen GHG Emissions – Different Biomass & Pathways

Life Cycle GHG Emissions (kgCO₂eq./kg H₂)

- Bio-hydrogen (Pyrolysis) - Whole Tree
- Bio-hydrogen (Pyrolysis) - Forest Residue
- Bio-hydrogen (Pyrolysis) - Wheat straw
- Bio-hydrogen (Gasification) - Whole Tree
- Bio-hydrogen (Gasification) - Forest Residue
- Bio-hydrogen (Gasification) - Wheat straw
HYDROGEN PATHWAYS: COMPARATIVE ECONOMIC AND ENVIRONMENTAL METRICS
Comparative Techno-Economics

Production Scale (tonnes/day)

Hydrogen Production Scale

- Wind-Hydrogen
- Hydro-Hydrogen
- Bio-hydrogen (Pyrolysis) - Whole Tree
- Bio-hydrogen (Pyrolysis) - Forest Residue
- Bio-hydrogen (Gasification) - Straw
- Bio-hydrogen (Gasification) - Whole Tree
- Bio-hydrogen (Gasification) - Forest Residue
- Agricultural...
- SMR-CCS
- UCG-CCS

* Data for Wind-Hydrogen, SMR-CCS and UCG-CCS from Olateju and Kumar, 2015

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Comparative Techno-Economics – Hydrogen Production Cost

*All production costs have an Internal Rate of Return (IRR) of 10%, other than UCG at 15%. All costs in $CAD 2016.

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Comparative GHG Economics/Footprint

<table>
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<tr>
<th>Process Type</th>
<th>Life Cycle GHG Emissions (kg CO₂ eq./kg H₂)</th>
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</thead>
<tbody>
<tr>
<td>Wind-Hydrogen</td>
<td>0.68</td>
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<tr>
<td>Hydro-Hydrogen</td>
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<tr>
<td>Bio-hydrogen (Pyrolysis) - Whole Tree</td>
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<td>Bio-hydrogen (Pyrolysis) - Forest Residue</td>
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<td>Bio-hydrogen (Gasification) - Whole Tree</td>
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<tr>
<td>SMR-CCS</td>
<td>6.02</td>
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<tr>
<td>UCG-CCS</td>
<td>1.26</td>
</tr>
</tbody>
</table>

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Comparative GHG Abatement Cost

GHG Mitigation Cost ($/tonne CO₂)

- Wind-Hydrogen: $325
- Hydrogen (Pyrolysis) - Whole Tree: $138
- Bio-hydrogen (Pyrolysis) - Forest Residue: $222
- Bio-hydrogen (Gasification) - Whole Tree: $370
- Bio-hydrogen (Gasification) - Forest Residue: $122
- Bio-hydrogen (Gasification) - Straw: $123
- SMR-CCS: $129
- UCG-CCS: $80
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Key Observations

• Biomass-based hydrogen has low GHG footprint compared to hydrogen from natural gas sources.
• Biomass-based hydrogen is more cost-efficient compared to other renewable source like wind.
• Biomass can provide baseload hydrogen production similar to natural gas.
• GHG abatement cost is higher than $100/tonne of CO2 mitigated.
• Biohydrogen could be one of the GHG mitigation pathways for oil sands with technology improvement and incentives.
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Contact Information:

Dr. AMIT KUMAR

Professor

NSERC/Cenovus/Alberta Innovates Associate Industrial Research Chair in Energy and Environmental Systems Engineering

Cenovus Energy Endowed Chair in Environmental Engineering

Department of Mechanical Engineering, University of Alberta

Amit.kumar@ualberta.ca

www.energysystems.ualberta.ca

+1 780 492 7797