Legacy Mines as Low Cost Bioreactors –
A "new paradigm" for bioconversion of coal with minimal environmental impacts

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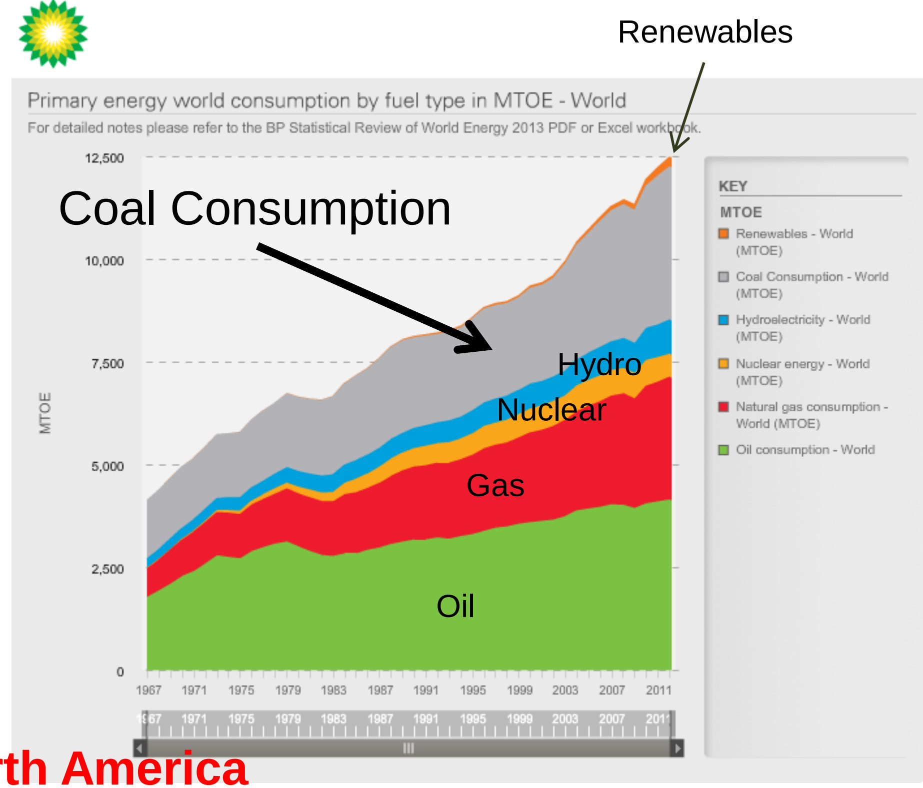
Points to Cover

- **The Challenge, Opportunity and Prize**
  - **Why worry or talk about coal?**
- **The Concept – Cape Breton Example**
- **CMC Project In-situ Coal to Fuels – A start**
- **Steps in Building the Concept**
  - **Including integration with biomass to energy**
- **Summary**
- **Acknowledgments**

The Challenge – Coal is a still a Growing Source of Energy in the World

- Poor or rapidly expanding economies need a low cost energy source
- Globally 1.3 billion people live without a reliable source of power
- Coal is mined in over 70 countries
- Industry employs over 7 million people
- Source: www.worldcoal.org



U.S./Canada – Can afford to switch to gas (At least for a while!)

- <u>Most other countries cannot</u>

- No gas resources of their own

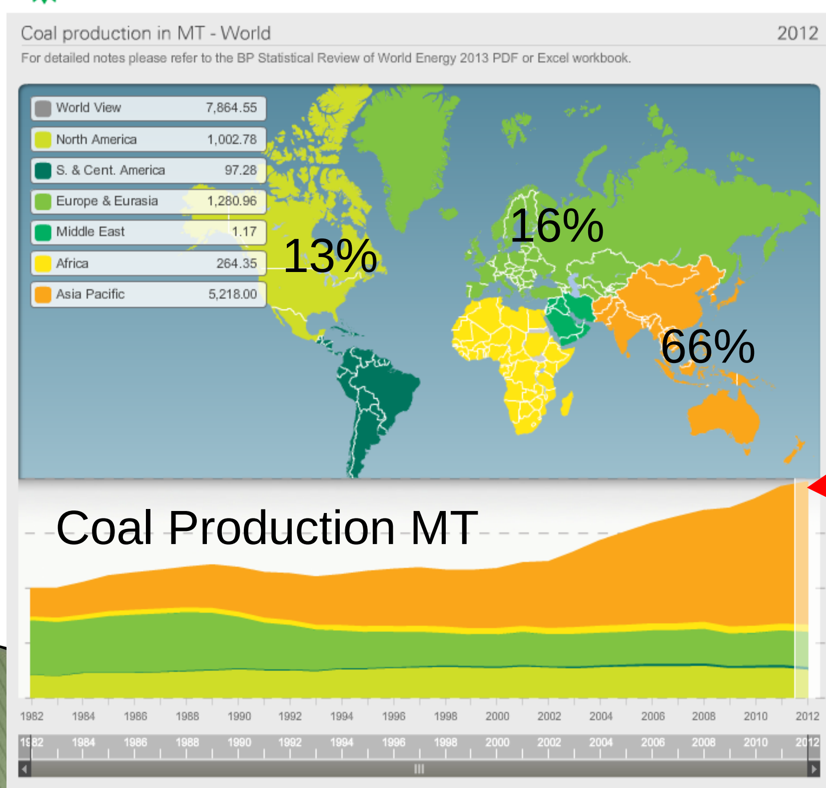
- Shale gas too expensive (water & $$)

- High priced gas everywhere except North America

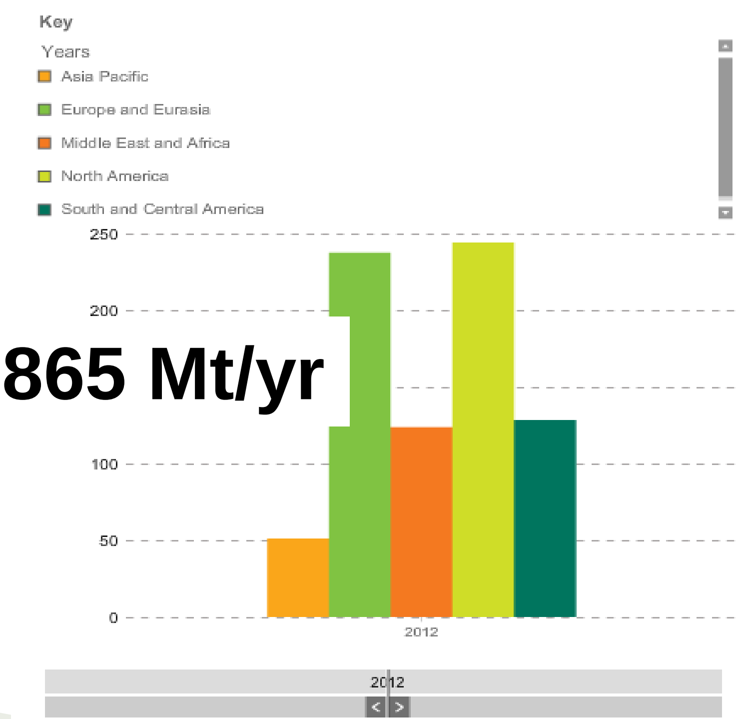
- Coal is usually the best and sometimes only option for developing regions

The Opportunity

- There is still a lot of mineable coal in the world, even more unmineable.
- World reserve/demand index ~109 years; Almost 250 years in U.S. and Europe/Eurasia; 50 years in SE Asia
- Too much for countries to ignore



7,865 Mt/yr



The Prize – Allow Coal Energy Extraction without the Negative Impacts of Coal

In-situ vs. Ex-Situ Coal Energy

- Reduce mining energy → minimize material mined
- Reduce loss of life → avoid people in U/G mines
- Increase resource that can be accessed → coal too deep or too hazardous to mine
- Minimize surface impacts → Reduce waste disposal at surface, accept biowastes and biomass
- Reduce emissions of GHGs, particulates, mercury, sulphur and water vapour
- **What are the "greener" options for coal?**

Well Studied Coal Power Options

Surface Mines
- Historic
- Outcrop
- Open Pit
- Mountain Top Removal

Subsurface Mines
- Historic
- Dry Land
- Subsea
- VAM – Ventilation Air Methane
- AMM – Abandoned Mine Methane

Unmineable
- CBM (Dry/Wet) Vertical Horizontal Multi-lateral
- Enhanced CBM CO_2/Flue Gas
- Bioenhanced CBM

Want to Eliminate

Uneconomic vs. gas

Low economics vs. shale gas

Surface thermal power generation
- Historic
- With Carbon Capture
- Oxycombustion

Ex-situ Thermal Gasification/Liquefaction of Coal

In-situ Thermal Gasification/Liquefaction of Coal

Ex-situ Bioconversion of Coal

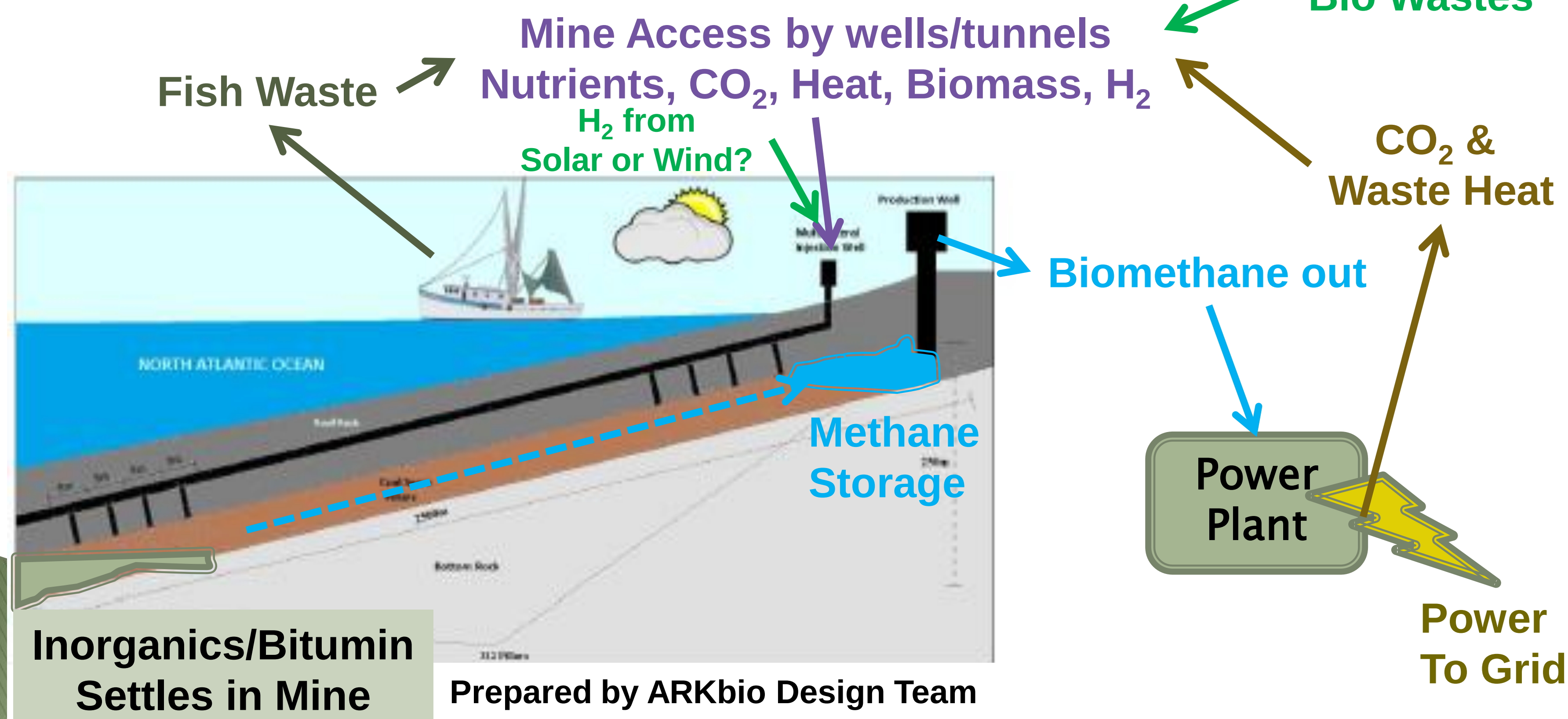
In-situ Bioconversion of Coal

What is this?

Legacy Coal Mines to Bioreactors

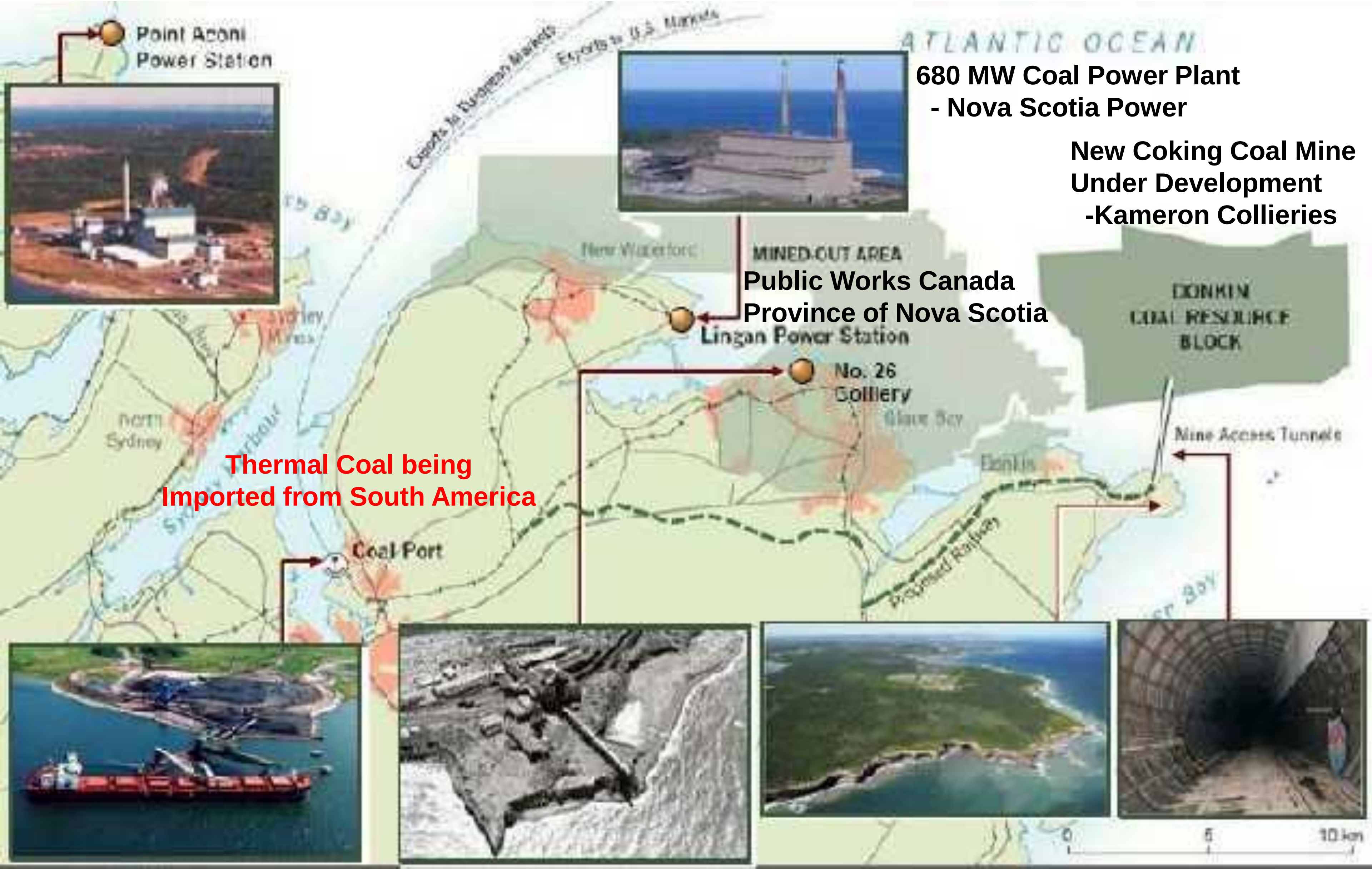
Example → Sydney Mines NS
- Access to Mine – Wells or Tunnels
- Fragment Remaining Pillars
- Circulate Fish Waste Nutrients
- Collect Methane @ High Point

Potential Enhancements
- Inject Heat/CO_2 from Power Plant
- Use CO_2 to extract Bitumen 1st
- Enhance mixing
- Enhance consortia
- Add biomass



Prepared by ARKbio Design Team

Cape Breton Opportunity



Cape Breton Opportunity

- **Greatest potential value in Canada → Cape Breton, Nova Scotia**
  - **Greatest impact on reducing GHGs and poverty → Developing countries**
- **Local coal power generation, importing coal from offshore**
  - Potential source of waste heat and CO_2/flue gas
- **Glace Bay Sewage Seepage into Underground Mines**
  - Problem to solve and opportunity to learn
- **Biomass Nutrients Available – Fish/Agriculture/Forestry**
  - Fish waste one of the better nutrients for enhancing bioconversion
- **Economic and Environmental Needs**
  - Mitigate impacts of legacy coal mines, while generating local jobs to support the economy → Integrate with low volume biomass
- **Clear Control of Mines → Public Works Canada and Province**
  - **Over 4000 km of mine tunnels, mapped, 40-50% of the coal remains**
  - **Bioreactor already contains over 250 billion litres of water**

How it Got Started

Carbon Management Canada
CMC-NCE

- Genome Canada-funded "Metagenomics for Greener Production and Extraction of Hydrocarbon Energy" or the "*Hydrocarbon Metagenomics Project (HMP)*" ~$10M
- CMC-NRC Project - ~$2.5M over 4 years (2010-2014)
  - "Bioconversion of Coal by Enhanced Engineering Pathways into Fuel products"
  - Started when gas was forecast to be in short supply → focus on enhancing CBM with bioconversion but could be applied to liquid fuels
  - Basic Objectives → What bioprocesses and where?
  - Acknowledgements: CMC, EnCana, Sherritt, NanoAlberta (AITF), GenomeCanada, GenomeAlberta

sherritt

encana natural gas

NanoAlberta (AITF)

GenomeCanada

GenomeAlberta

"It takes a village…"

J. Foght

G. Southam

K. Budwill

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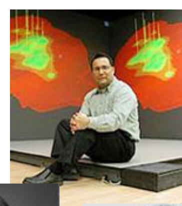

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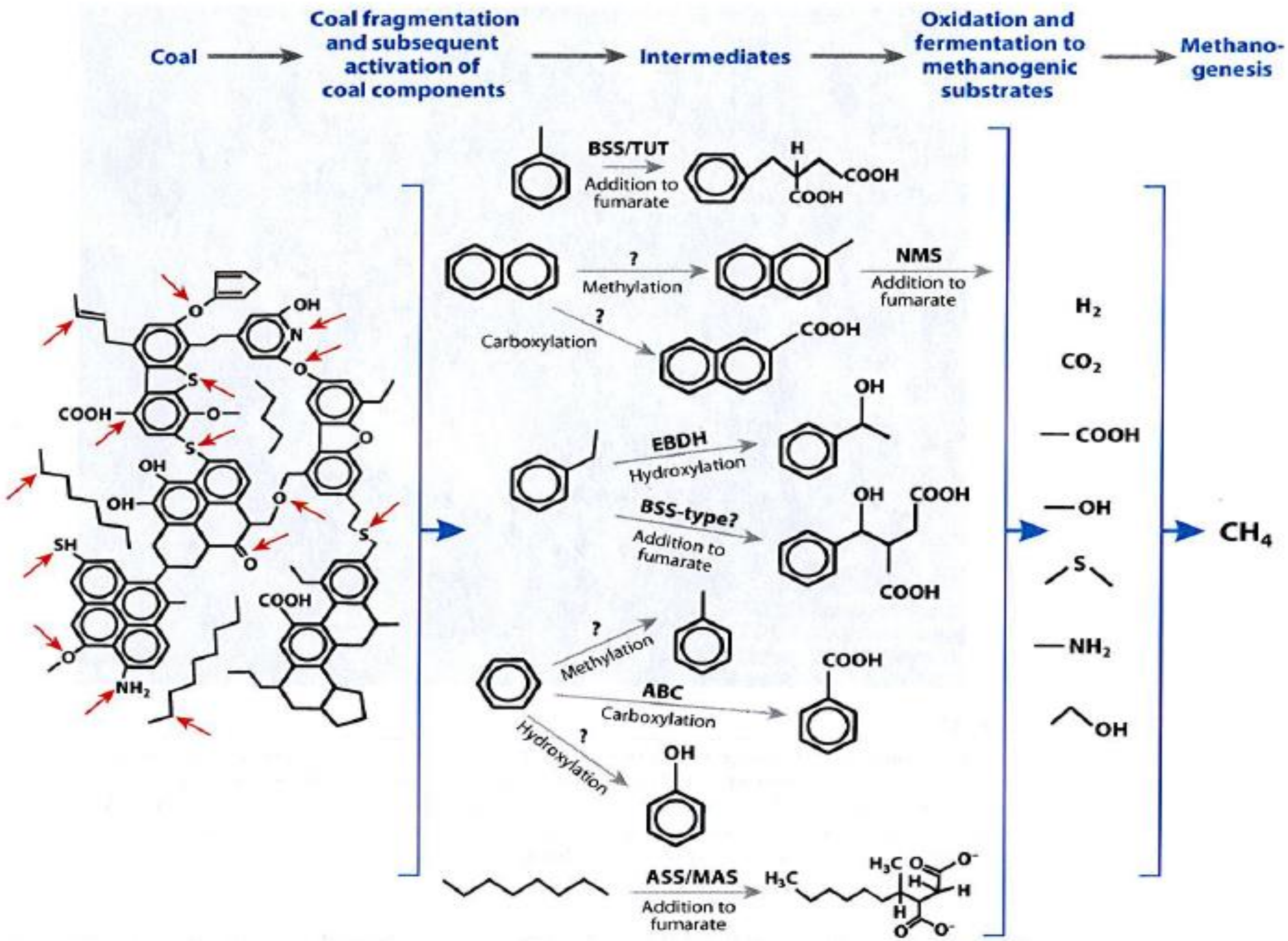
Engineers

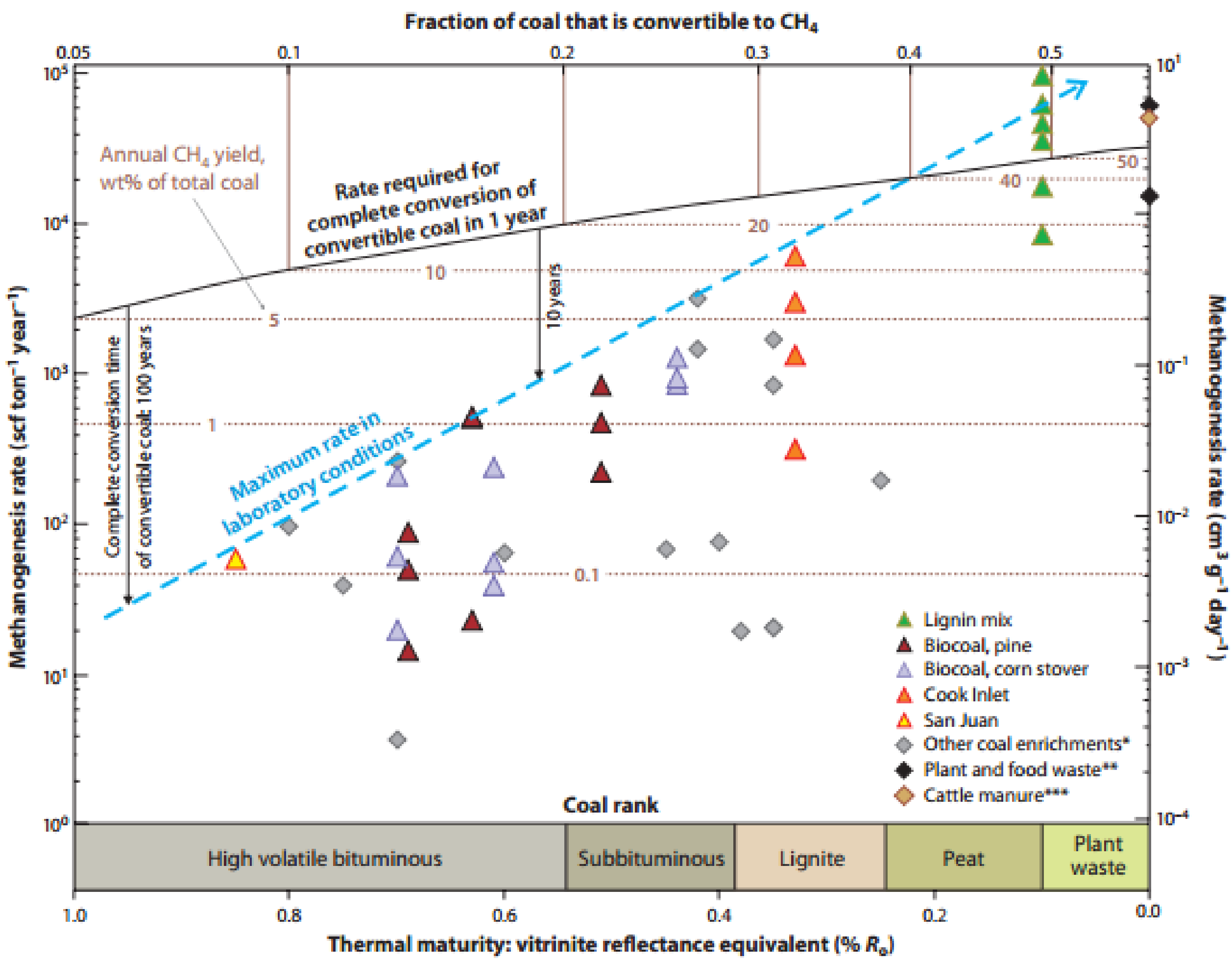
Microbial Conversion of Coal to Methane



From: Strąpoć et al., 2011, Annu. Rev. Earth Planet Sci. 39:617-656

Low Rank Coals Preferred

- Lab Scale Batch Tests Results →Continuum
  - Plant waste → Peat → Coal



Research gaps addressed

Effect of coal rank on bioconversion

Effect of redox conditions on bioconversion

What components of coal are amenable to bioconversion?

Microbial communities: who's there, what are they doing?

What components of coal limit or inhibit bioconversion?

Interaction of microbes with coal surface

What are the intermediate by-products?

Role of water

Mass transport limitations

Reservoir-scale logistics

Steps in Building the Concept

Motivation	Overcome #keepitintheground → show benefits GE^{3}LS- Genomics, Economics, Environment, Ethics, Legal, Social
Basic Science	Build on Prior Work → New conditions in legacy mines Work to build yields, conversion, other products, enhancements
Design of Mine Bioreactors	Access, circulation, isolation, mitigation, enhancements Address options: simple → complex; coal mines vs. other mines Impact on net cost of generating gas vs. local gas/coal costs
Best Applications	Co-location of legacy mines, nutrients, other biomass Where are economics favoured over other local energy sources
Integration	Integration to Enhance Benefits Power, carbon capture, biomass processing, biorefinery complex

A. Motivation

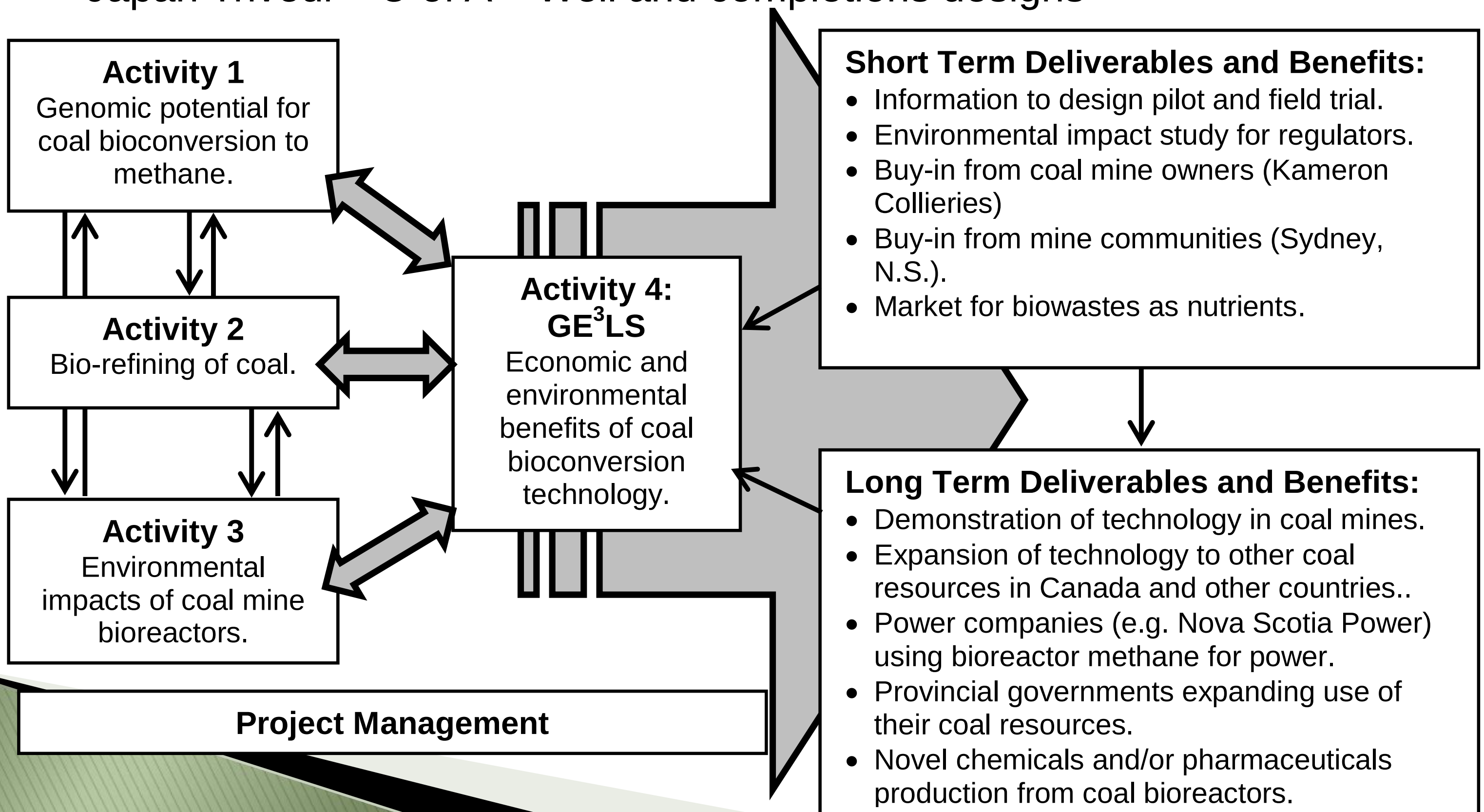
- Track A.1 – High Level Benefits, Issues & Opportunities
  - Local, Regional and Global
  - Briefing Notes/Papers, FACT Sheets, FAQS
- Track A.2 - Road maps - mine design options, mitigation
  - Cost of conversion vs. yields and rates; technology needs
  - Indicator: $/GJ vs. local gas price
- Track A.3 – Development of Teams and Collaborations
  - The “village” must get bigger – national/international
- Track A.4 - GE^{3}LS overall analysis of benefits and motivation
  - Local (Cape Breton NS,Drumheller AB, Nanaimo BC)
  - Regional (Atlantic, Prairies, Central, West Coast)
  - National (Canada, U.S., China, India, South Africa, Europe)

B. Basic Science

- Track B.1 – Biological/genomic enhancement
  - Based on Genome Canada 2015 pre-proposal – Bottle to small scale pilot
  - Basic science is proven for coal to gas → need better information on ways to improve yield and conversion, impacted by:
    - Coal particle size, temperature, pressure, nutrients, mixing, oxidation, CO_2, type of coal
- Track B.2 – Biological/genomic biorefining (in-situ & ex-situ) of coal to liquid products
  - More value added, large volume bulk products (acetone, ethanol)
- Track B.3 – Integration of Bioreactors
  - Adding biomass to coal mine bioreactors
  - Impacts of mine components on bioreactors (non-coal mines)

Basic Science Team:

Martin Mkandawire – Mine Researcher – Cape Breton University
Karen Budwill – Alberta Innovates Technology Futures – 10 yrs on CBM
Bruce Peachey – New Paradigm Engineering Ltd – Technology Roadmaps
Steven Hallam – UBC – Biorefining, metagenomics, fosmid library
Robert Beiko – Dalhousie – Bioinfomatics Analyses
Peter Dunfield – U of C – Bioinfomatics Analyses
Joule Bergerson – U of C – GE^3LS Studies
Patrick Hettariachi – U of C – Methanotroph → Mine methane mitigation
Beth Mason – Cape Breton University – Biologist, Bio-products
Japan Trivedi – U of A – Well and completions designs



C. Design of Mine Bioreactors

- Track C.1 – Accessing mines → convert into bioreactors
  - Simple – use existing tunnels → run pipe down tunnels
  - Complex – drill wells to specific sites, block tunnels, break-up coal
- Track C.2 – Optimize biogas production
  - Pre-treatment – Partially oxidize to form precursors
  - Staged – Enhance CBM/store heat → inject CO_2 → produce CH_4
- Track C.3 – Impact of mine type on biorefining
  - By products and side reactions with mine walls vs. stainless steel
- Track C.4 – Coal Mine Environmental Impact Mitigation
  - Water quality/balance, air emissions vs. coal, GHG net balance, land footprint vs. surface alternatives, extinguish coal seam fires
- Track C.5 – Verschuren as an International Centre for Legacy Coal Mine Utilization

D. Target Resources

- Track D.1 – Focus on Sydney Mines Cape Breton
  - Current focus as the best site in Canada for numerous reasons for demonstration → High GE^3LS Potential
- Track D.2 – Other Canadian locations for coal to biogas
  - Work with Coal Association of Canada, Biosources (nutrients and biomass) and Power Generation/Transmission infrastructure
- Track D.3 – International locations for coal to biogas
  - Assessing countries with coal resources and power demand
  - E.g. UK had its first day with no coal power generation to grid
- Track D.4 – Biomass and Peat Bioprocessing
  - Potential option in Canadian shield, mountains for locations with hard-rock mines and peat, but no coal

E. Integration with Other Processes

- Track E.1 – Power Generation Systems
  - Use low quality waste heat and CO_2
- Track E.2 – GHG emissions reduction processes
  - Build on enhanced coal bed methane in mines
  - Carbonated water storage of CO_2, react CO_2 to chemically sequester it
- Track E.3 – Surface Biorefining Complexes
  - Synergies of having biofuels, biochemicals at the same site
- Track E.4 – Extraction value added bioproducts
  - What other high volume bio products could be produce in legacy mines?

Summary

- Coal still has a role in meeting world energy demand
  - Requires development of new methods of using it
- In-situ bioconversion of coal has potential value
  - Cape Breton identified as having near-term potential → gain knowledge → global potential to reduce GHG emissions and poverty in developing countries
- Genome Canada & CMC work provided the 1st steps
  - Further work is needed to take advantage of it
- Initial next steps require funding and partners
  - Not taking the next steps may result in significant losses in opportunities if energy system transitions are missed
- Expanded multi-disciplinary teams pursuing the concepts → looking for motivated collaborators. Contact us if you are interested in moving this concept further

Acknowledgements

- Genome Canada (HMP) and CMC-NRC (Engineering Pathways) for funding original steps
  - Also partners such as Encana and Sherritt
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