# AN INTEGRATED APPROACH TO ENERGY RESEARCH AND TECHNOLOGY DEVELOPMENT

*Draft for Discussion*

# Executive Summary

The energy sector accounts for about one half of the Alberta economy, taking into account direct and indirect impacts, and is a significant contributor to the Canadian economy. This sector continues to be an important driver for knowledge-based industries and diversification. However, the energy industry is facing enormous and complex challenges to transition rapidly to sustainable, clean energy development. Increasing constraints on conventional resource availability, water, the environment, greenhouse gas emissions, and policy will severely limit the development of competitive energy supplies.

To tackle the major challenges facing the energy sector requires a revitalized energy effort with significant increases in research and technology investments. The real opportunity is in providing a secure and lasting energy supply, while at the same time, substantially lowering carbon emissions and expanding economic growth and revenues to the Alberta treasury.

The Alberta Energy Research Institute plays a key role in identifying research and technology that will play a role in sustaining Alberta's energy supply. AERI invests in research and assists in tracking technologies from initial concept through to development and commercialization. This document is an extension of AERI's Energy Research Plan (www.aeri.ab.ca), which describes AERI's vision, mission, role, strategic plan, and goals. The Strategic Plan also describes the process to achieve the goals, based on the following objectives: balanced portfolio, program integrator, research intelligence, support university energy research, and technology transfer.

The current document was developed by the AERI research managers, assisted by staff from Alberta Energy and Alberta Environment, to ensure that R&D focuses on strategic program area and defines a balanced portfolio encompassing the full technology development path from early stage research to development and commercialization. The portfolio is based on information from the technology roadmaps, the work of the Clean Hydrocarbon Technology Futures group, three staff workshops held in Fall 2002, and industry consultation.

AERI has identified seven priorities for research and technology development, which have the most technological potential for large benefits:

- **Geological storage of $CO_2$** from hydrocarbon production sources, including research on reliability and safety. The storage of $CO_2$ may be combined with enhancing production from conventional oil and coalbed methane.
- **Adaptation of integrated gasification and combined cycle** (IGCC) technology suited to a wide variety of Alberta feedstocks and designed for power generation with flexibility for the co-production of hydrogen, synthetic natural gas, chemicals, and other valuable products.

- **Catalytic upgrading research and development** focused on less energy intensive upgrading and synthetic crude designed for North American refineries.
- **Lower intensity oil sands production** and a focus on in situ technologies (such as VAPEX and in situ combustion) that significantly decreases reliance on natural gas and water.
- **Water research and technology program** to help unlock the potential of coalbed methane, and includes oil sands tailings and oilfield water reuse.
- **Establish a dedicated hydrogen production, storage, and infrastructure research and fuel cell demonstration program** with a techno-economic focus on fuel cells and on alternative energy sources that would bridge the gap between the current Hydrocarbon Economy and the future Hydrogen Economy.
- **Utilize solvent deasphalting processes** to separate easily refined fractions from the more difficult to upgrade asphaltenes, and develop alternative uses for the heavier ends.

An eighth, and critical, strategic priority is exploring how different technologies interact, and benefit more than one of the areas targeted in the Alberta Energy Research Strategy, as is shown in the following table:

| Priority Research and Technology | Strategic Areas | | | | | |
|---|---|---|---|---|---|---|
| | Overall Priority | Clean Coal | Improved Oil Recovery | Upgrading Technology | Carbon & Water Management | Alternative Energy |
| **Geological Storage of $CO_2$** | 1 | ● | ● | ○ | ● | ○ |
| **Gasification** | 2 | ● | ○ | ● | ○ | ○ |
| **Catalytic Processes** | 1 | ● | ○ | ● | ○ | ● |
| **In Situ Oil Sands Technologies** | 3 | N/A | ● | ○ | ● | ○ |
| **Water Treatment Technologies** | 3 | ○ | ● | ○ | ● | N/A |
| **Hydrogen Technologies** | 2 | ○ | ○ | ● | ○ | ● |
| **Solvent Deasphalting** | 2 | N/A | ● | ● | ● | N/A |

● Major Impacts ○ Secondary Impacts

The number of strategic areas impacted for each item in the Research and Technology column determines its overall priority ranking.

# Process for Developing Priorities & a Balanced Portfolio

Based on the information from the Technology Roadmaps and Clean Hydrocarbon Technology Futures, the Alberta Energy Research Institute (AERI) Research Managers, assisted by staff from Alberta Energy and Alberta Environment, used the following process for developing priorities and a balanced R&DD portfolio:

## Current and Desired Future States

Define the key technical and economic features of each strategic area: (a) as it exists currently, and (b) if anticipated technological advances are successful in increasing the long-term competitiveness of the industry in that sector.

## Gaps

Identify the gaps that exist between the current and the desired future states. This is intended to identify the business and technology advances needed to bridge the gap between the current state and the desired future state.

## R&D Objectives

Identify the R&D needed to achieve specific technical advances.

## Impact Criteria

The impact criteria assume that the technology will be successfully implemented:

- **Climate Change:** Potential to reduce emission intensities and environmental footprint.
- **Economic Growth and Competitiveness:** Will it help the industry to grow its local and international markets?

## Achievability Criteria

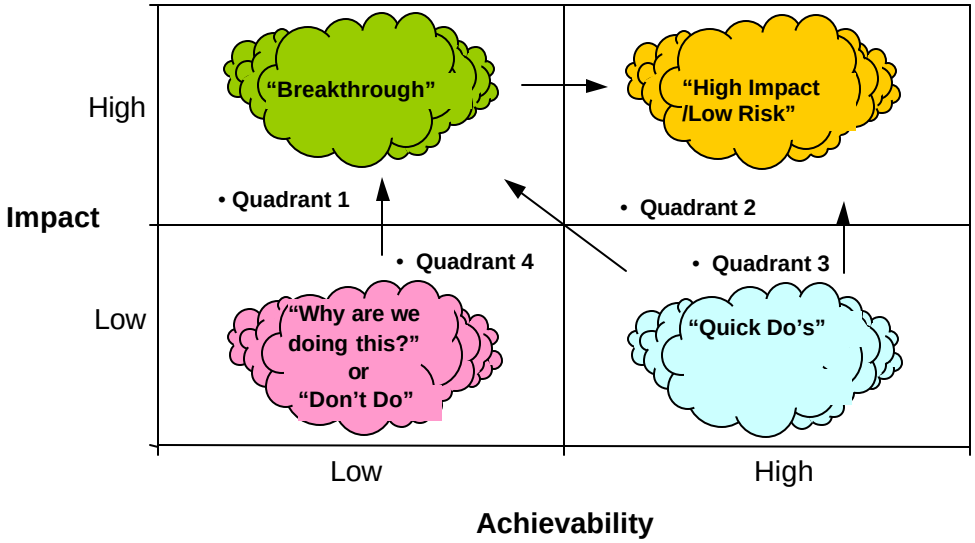
- **Technical Achievability:** Examples: Maturity and stage of development (position on S-curve); basic understanding of underlying principles, extent of background knowledge. Is there a technical/scientific champion capable of leading the technical/scientific development?
- **Market/Business Achievability:** Examples: Is there a committed or potential strong private sector champion, joint venture partner or early adopter capable of commercializing the concept/technology?

## Balanced R&D Portfolio

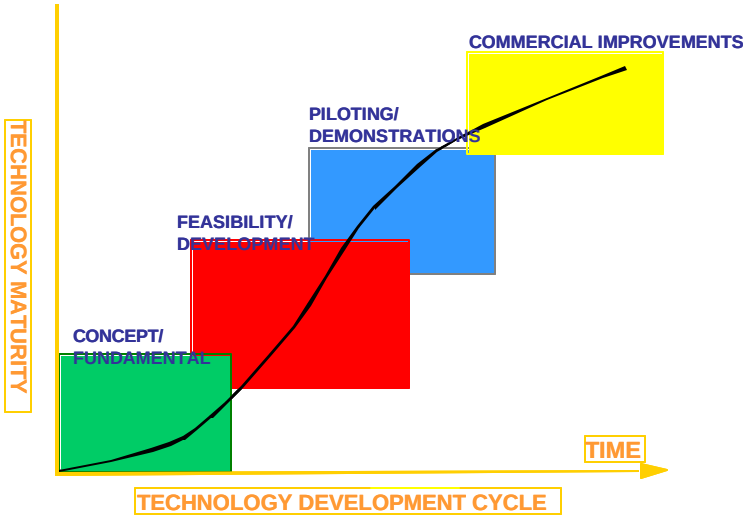
AERI's objective is to invest in a mix of R&D activities which maintains a balance among the Impact, Achievability, Stage of Development, and leverage of AERI's investment.

## Impact vs. Achievability Matrix

Research objectives are analyzed, assigned Impact and Achievability ratings, and plotted on the grid shown below. The grid aids in developing a portfolio balancing Impact and Achievability (Risk), as well as the staged R&D needed to improve impact and achievability.




## Stage of Development (Position on S-curve)




The S-curve plot aids in the selection of R&D objectives distributed along the full technology development path, as well as the staged R&D needed to advance along the S-curve. The plot also acts as a guide for AERI's investment leverage ratio (external/AERI investment), which increases as technology matures.

# Summary of Strategic Research Area Objectives

The following summarizes the research and development objectives in each of the five strategic areas of the Alberta Energy Research Strategy. The tables in each section use the color ranking scheme shown below:

**Overall Priority**

Low, Medium, High

**Climate Change Rating (Potential for Reducing GHG's)**

Low, Medium, High

**Economic Impact/Competitiveness Rating (Potential for Improving Competitiveness and Contributing to Alberta's Economic Development)**

Low, Medium, High

**Maturity (Position on S-Curve) and Leverage (External/Internal) of AERI Investment (Characterization of R&D According to Stage of Development and Leverage of AERI's Investment )**

| Characterization | Maturity (Position on S-Curve) | Leverage |
|---|---|---|
| ■ | Early Stage (Long Term Scientific) | Low (1:1) |
| ▲ | Intermediate Stage (Development) | Intermediate (1-5) |
| ✚ | Advanced Stage (Demonstration/Commercialization) | High (>5) |

# Clean Coal

## Current State

- Coal has traditionally provided stable, low-cost electricity to Albertans. However, because it is seen as a "dirty" fuel, and there are uncertainties about emissions standards and implementing Kyoto Protocol targets, it is no longer the fuel of choice for power plants.
- There is a shift to building smaller, lower-cost, gas-fired plants for electricity generation. Although gas-fired plants have a cleaner image, and shorter approval and start-up times, fluctuating gas prices have resulted in uncertain and unstable electricity prices. Nuclear power is not a credible option. Hydroelectricity sources are not adequate. Alberta has to rely on coal for its power generation.
- High costs and technical risks have delayed new Integrated Gasification Combined Cycle (IGCC) plants from being built.

## Desired Future State

- Commercially proven and cost effective technologies for new and retrofitted clean coal power generation with $CO_2$ capture.
- Stable and competitive electricity prices for Alberta industries, based on balanced development of clean coal, gas-fired plants and alternative energy developments
- Development of hybrid gasification systems capable of producing clean power, synthesis gases, hydrogen, chemicals from a variety of feedstocks (coal, coke, oil sands residues, biomass), and capturing $CO_2$ for commercial applications or sequestration.

| **Economic Development** | **Environmental Factors** |
|---|---|
| Alberta will have a cost-competitive & sustainable supply of electricity, based on a long-term supply of coal. | All emissions, including carbon dioxide, from power plants would be reduced to near-zero levels |
| Coal gasification would provide Alberta with alternative sources of methane and hydrogen. | Carbon dioxide emissions would be captured and injected into depleted oil reservoirs and coal seams to recover more oil and methane |

## R&D Objectives

| AREA | Objectives | Overall Priority | Climate Change | Economic Impact | Maturity & Leverage |
|---|---|---|---|---|---|
| **Emissions from Existing Coal Plants** | Inventory of trace elements in Alberta coals |  |  |  |  |
| | Pre-combustion beneficiation of coal (university based) |  |  |  |  |
| | Retrofit technologies for $CO_2$ capture. |  |  |  |  |
| | Multi-pollutant control technologies |  |  |  |  |
| **Integrated Gasification Combined Cycle (IGCC) Systems** | Technology evaluation & adaptation |  |  |  |  |
| | R&D, process & systems enhancements & optimization |  |  |  |  |
| | Technology integration & demonstration |  |  |  |  |
| **Hybrid Systems (Multi-fuel and product systems)** | Technology evaluation & adaptation |  |  |  |  |
| | R&D process and system optimization |  |  |  |  |
| | Technology integration, optimization & demonstration |  |  |  |  |
| **Novel Techno-logies (e.g. hydrogasification)** | Evaluate novel Concepts |  |  |  |  |
| | R&D process & system optimization |  |  |  |  |
| | Development, adaptation, optimization & integration |  |  |  |  |

| Low | Medium | High | **Priorities** |
|---|---|---|---|
|  |  |  | **Maturity** |

# Improved Recovery

## Current State

- Conventional oil production and discoveries are declining in Alberta. New focus and investment is on oil sands production or offshore. There are no commercial coalbed methane recovery projects in Alberta.
- Low return on heavy oil investments relative to other investment opportunities.
- Uncertainty over energy price fluctuations, and the impact of Kyoto on bitumen recovery operations.

## Desired Future State

- Increased industry investment to develop conventional oil reserves in Alberta.
- Competitive and cost effective bitumen and heavy oil operations.
- Efficient use of energy in thermal recovery, and proven commercial non-thermal recovery alternatives.

| **Economic Development** | **Environmental Factors** |
|---|---|
| New technologies are needed to ensure that the government's royalty revenues do not decline sharply | The need to sequester carbon dioxide and other greenhouse gases provides an opportunity to develop new oil and gas recovery processes |
| New technologies are needed to ensure that capital investment in the energy sector remains high | |

## R&D Objectives

| AREA | Objectives | Overall Priority | Climate Change | Economic Impact | Maturity & Leverage |
|---|---|---|---|---|---|
| **Conventional Oil** | Waste stream $CO_2$ EOR demonstration |  |  |  |  |
| | Emerging EOR technologies, such as microbial EOR |  |  |  |  |
| **Heavy Oil & In Situ** | Solvent-based recovery processes |  |  |  |  |
| | Increased efficiency of heavy oil operations |  |  |  |  |
| | Steam Assisted Gravity Drainage (SAGD) optimization |  |  |  |  |

| AREA | Objectives | Overall Priority | Climate Change | Economic Impact | Maturity & Leverage |
|---|---|---|---|---|---|
| | VAPEX demonstration | ● | ● | ● | ▲ |
| | Thermal demonstration | ● | ● | ● | ▲ |
| **Mined Oilsands** | Leading-edge environmental technologies | ● | ● | ● | ■ |
| **Natural Gas** | Conformance control technologies | ● | ● | ● | ▲ |
| **Coalbed Methane** | Investigation into Alberta coalbed geomechanics | ● | ● | ● | ■ |
| | CBM water quality & disposal study | ● | ● | ● | ■ |
| | ECBM field pilot | ● | ● | ● | ▲ |
| | CBM resource delineation | ● | ● | ● | ■ |

| Low | Medium | High | **Priorities** |
|---|---|---|---|
| ■ | ▲ | ✚ | **Maturity** |

# Upgrading

## Current State

- The market for synthetic crude oil (SCO) is shrinking. Fewer refineries are able or willing to accept our SCO because of quality constraints. Shortage of diluent used to transport bitumen to U.S. markets.
- Existing upgrading processes have high capital and operating costs. Emissions from producing the hydrogen needed for upgrading are high, as are the levels of energy consumption required. There are severe problems with pollution in the waste-water stream, and disposal of coke byproducts.

## Desired Future State

- SCO that meets quality specifications for the majority of North American refineries.
- Flexible, low capital cost technology solutions to meet site-specific requirements for upgrading of in situ heavy oil and bitumen.
- Flexible, multiproduct slate to meet changing markets and maximize value of produced bitumen with near zero emissions (gas, liquid, and solid).

| Economic Development | Environmental Factors |
|---|---|
| More upgrading in Alberta means that more of the value of the resource remains here | Higher-efficiency processes imply lower carbon dioxide emissions and lower costs |
| Diluent availability and pipelining constraints may hamper the development of the heavy oil industry, unless better upgrading technologies are developed | Techniques for coke and waste water disposal would improve the viability and sustainability of this industry |

## R&D Objectives

| AREA | Objectives | Overall Priority | Climate Change | Economic Impact | Maturity & Leverage |
|---|---|---|---|---|---|
| **Mined Oil Sands to SCO** | New and improved "clean" upgrading processes, catalysis | ● | ● | ● | ■ |
| | Lower capital and operating cost processes through new and improved materials and catalysts | ● | ● | ● | ■ |
| | Reduce emissions and energy intensity of hydrogen production from other sources | ● | ● | ● | ■ |
| **In Situ Oil Sands** | In situ upgrading (e.g. bio-upgrading) and high grading (e.g. solvent extraction) | ● | ● | ● | ■ |
| | Field/Partial upgrading | ● | ● | ● | ▲ |
| | Diluent replacement technologies (SCO, $CO_2$, water, hot pipelining, etc.) | ● | ● | ● | ▲ |
| | Flexible, modular upgrading units | ● | ● | ● | ■ |
| **Hybrid Systems** | Technologies to optimize SCO and petrochemical feedstocks | ● | ● | ● | ■ |
| | Technologies to produce $H_2$ from coke and heavy residuals (gasification) | ● | ● | ● | ■ |
| | Technologies to produce SNG and ultra-clean liquid fuels through synthesis routes | ● | ● | ● | ■ |

| Low | Medium | High | Priorities |
|---|---|---|---|
| ■ | ▲ | ✚ | Maturity |

# Alternative Energy

## Current State

- High cost of hydrogen produced from natural gas.
- High cost of infrastructure for generating and distributing hydrogen.
- High cost and low electric generating capacity of existing fuel cell technology.
- Fuel cell R&D in Alberta is at an early stage in development.
- Limited application of other alternative energy sources (hydro, wind, biofuels).

## Desired Future State

- Alternative and competitive sources of hydrogen, e.g. gasification, and well-developed hydrogen distribution infrastructure.
- Affordable fuel cell technologies for distributed power generation.
- Alberta has a mix of conventional and alternative energy sources.

| **Economic Development** | **Environmental Factors** |
|---|---|
| Alberta should lead the orderly transition from a hydrocarbon economy to a hydrogen economy | The development of renewable technologies would help Alberta meets is climate change obligations |
| The integration of the energy, forestry and agricultural sectors in Alberta would sustain the Alberta Advantage for several generations | |

## R&D Objectives

| AREA | Objectives | Overall Priority | Climate Change | Economic Impact | Maturity & Leverage |
|---|---|---|---|---|---|
| **Hydrogen** | Testing of various low grade Alberta hydrocarbon fuels for gasification and syngas production |  |  |  |  |
| | Improved gasification and separation processes (membranes, catalysts) |  |  |  |  |
| | Improved hydrogen storage, (high pressure tanks, metal hydrides, carbon nanotubes, and glass microspheres) |  |  |  |  |

| AREA | Objectives | Overall Priority | Climate Change | Economic Impact | Maturity & Leverage |
|---|---|---|---|---|---|
| | Hydrogen pipeline stress & corrosion cracking issues | ● | ● | ● | ■ |
| **Fuel Cells** | Demonstrate a fuel cell system in Alberta for public education, outreach, and combined heat and power purposes. | ● | ● | ● | ■ |
| | Cost effective coal/bitumen utilization into an acceptable feed for fuel cells | ● | ● | ● | ■ |
| | Fuel cell for the conversion to value-added petrochemical products. | ● | ● | ● | ■ |
| **Bio-Energy** | Utilization of biological sinks for $CO_2$ sequestration | ● | ● | ● | ▲ |

| Low | Medium | High | **Priorities** |
|---|---|---|---|
| ■ | ▲ | ✚ | **Maturity** |

# Carbon and Water Management

## Current State

- High energy requirements and high emissions from Alberta's oil and gas, and power, industries.
- Lack of technology and infrastructure for economic capture and distribution of $CO_2$.
- High water usage of Alberta's energy industry, and lack of cost-effective water purification technologies. Competition for water with the agricultural industry.

## Desired Future State

- Improved efficiency of Alberta's energy industry, leading to lower intensity of $CO_2$ emissions.
- Near zero emission power generation technologies (e.g. IGCC) with $CO_2$ capture, distribution, and utilization and sequestration.
- Lower water use by the oil and gas industries. Cost-effective water recycle systems and purification technologies.
- Effective water management practices meeting the needs of the agriculture and energy industries.

| Economic Development | Environmental Factors |
|---|---|
| Carbon management would convert an environmental challenge into an economic opportunity | Carbon management would help Alberta meet its climate change challenge |
| Addressing water management issues would ensure the sustainability of energy production in the province | Water management is an opportunity for the province to effectively adapt to climate change |

## R&D Objectives

| AREA | Objectives | Overall Priority | Climate Change | Economic Impact | Maturity & Leverage |
|---|---|---|---|---|---|
| **$CO_2$ Capture** | Total capture of GHGs with lower energy requirements. | ● | ● | ● | ■ |
| | Lower cost and more efficient IGCC systems for coal. | ● | ● | ● | ■ |
| | More efficient power sources, such as fuel cells. | ● | ● | ● | ▲ |
| | Efficient, low-cost purification processes for $CO_2$. | ● | ● | ● | ▲ |
| | Technology to use low purity $CO_2$ in hydrocarbon recovery and sequestration. | ● | ● | ● | ▲ |
| **$CO_2$ Transport and Storage** | Infrastructure to move $CO_2$ from source to end user. | ● | ● | ● | ▲ |
| | Determine effect of impurities (such as $SO_2$, $H_2S$, $O_2$) on pipeline materials. | ● | ● | ● | ■ |
| | Improve knowledge of hydrates (prevent plugging of pipelines). | ● | ● | ● | ▲ |
| **$CO_2$ Sequestration and Use for H/C Recovery** | Technology for capture and injection of low purity $CO_2$. | ● | ● | ● | ▲ |
| | Determine ultimate storage capacity for $CO_2$ in Alberta. | ● | ● | ● | ▲ |
| | Otimize hydrocarbon recovery using $CO_2$ flooding. | ● | ● | ● | ■ |
| **Water Use and** | Replace water usage in production processes | ● | ● | ● | ■ |

| AREA | Objectives | Overall Priority | Climate Change | Economic Impact | Maturity & Leverage |
|---|---|---|---|---|---|
| **and Cleanup** | Clean produced water to agricultural standards. | ● | ● | ● | ■ |
| | Leave water in formation (e.g. separation processes). | ● | ● | ● | ■ |
| | Prevent water infiltration into producing formations. | ● | ● | ● | ■ |

| Low | Medium | High | **Priorities** |
|---|---|---|---|
| ■ | ▲ | ✚ | **Maturity** |