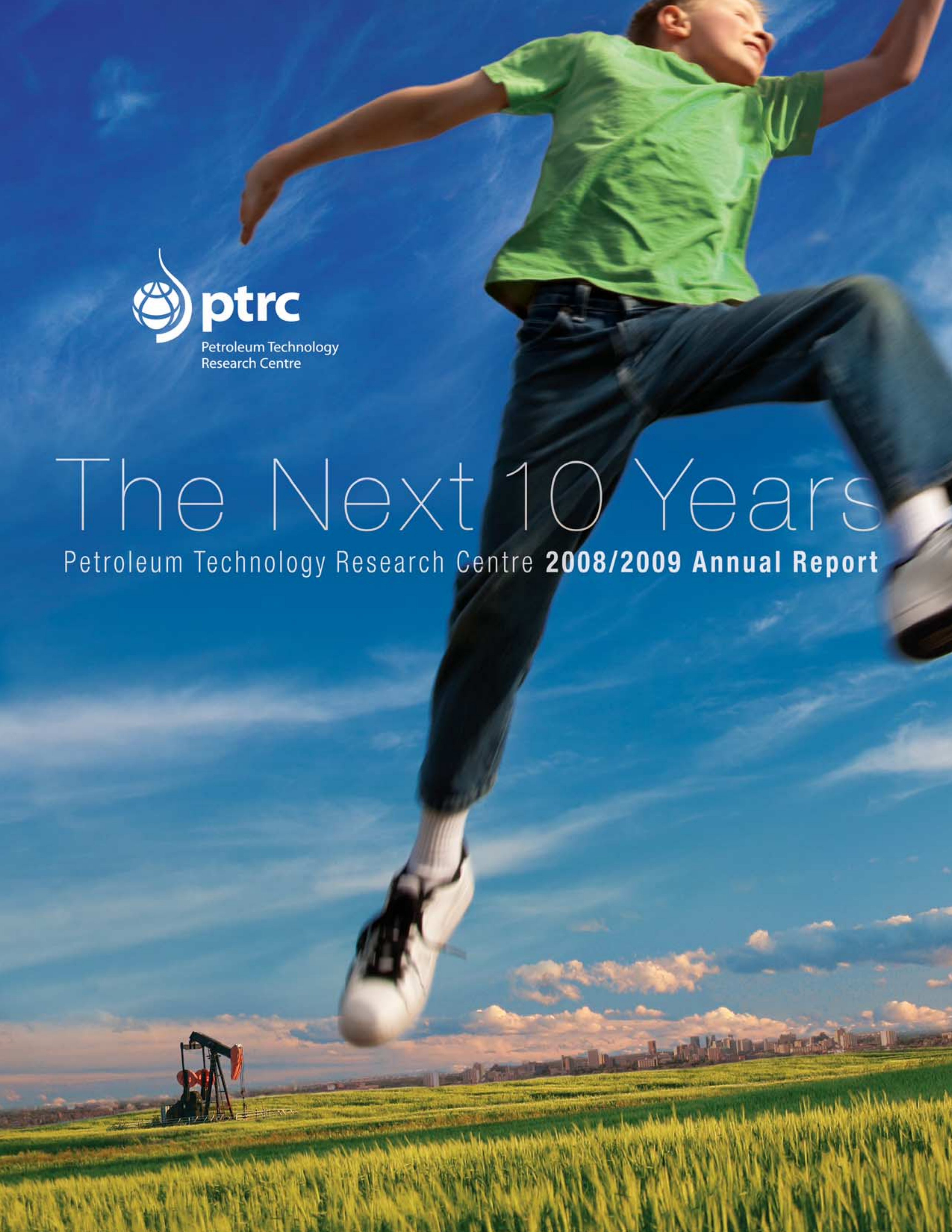

ptrc
Petroleum Technology
Research Centre

The Next 10 Years

Petroleum Technology Research Centre **2008/2009 Annual Report**

Front cover: The PTRC's Executive Director's son, Andrew Dawson, nine years old, leaps into Saskatchewan's secure energy future. The province has achieved status as a world leader in energy technology research, development and deployment.

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the next 10 Years

PTRC Description and Mission Statement

Description of the PTRC

The Petroleum Technology Research Centre (PTRC) is a not-for-profit corporation founded in 1998 by the University of Regina, the Saskatchewan Research Council, Saskatchewan Energy and Resources, and Natural Resources Canada. It is located in the Innovation Place Research Park in Regina, Saskatchewan, adjacent to the University of Regina campus. Its diverse portfolio of research projects is funded through ongoing contributions from several federal, provincial and private sector partners, including direct funding from:

- Government of Canada: Western Economic Diversification, Sustainable Development Technology Canada, Networks of Centres of Excellence, and Natural Resources Canada.
- Saskatchewan Government: Ministry of Energy and Resources, Ministry of Environment, Enterprise Saskatchewan.
- Private sector: Western Canadian and internationally based oil and gas companies, utilities and technology providers.

In addition, in-kind research support is provided by the University of Regina's Petroleum Engineering faculty and the Energy Division of the Saskatchewan Research Council – both of which are housed in the PTRC building.

The PTRC is governed by a Board of Directors comprising representatives of the founding partners and of industry leaders operating in western Canada. Its laboratory and modeling (physical and numerical) facilities in Regina, shared with the University of Regina and Saskatchewan Research Council, are among the most advanced and complete in North America.

PTRC Mission Statement

The PTRC's mission is to develop world-leading enhanced oil recovery and CO_2 geological storage technologies that ensure sustainable and environmentally sensitive development of Canada's energy resources. The PTRC manages enhanced oil recovery research and delivers basic and applied research results and technologies to its partners for field application. It serves as the managing agency for major research consortia. The organization enables governments and industry to combine resources and fund research in areas thought to be key to the nation's and, by extension, the world's energy security.

The PTRC building is located in Regina, Saskatchewan, in the Innovation Place Research Park.

Message from the Chair

The PTRC turned 10 years old during fiscal year 2008-2009, and in September the organization entered its second decade. It's been my view over the years that the excellent work the PTRC does – through such world-class research providers as the Saskatchewan Research Council, the Alberta Research Council, and the Universities of Regina, Saskatchewan, Alberta and Calgary – frequently happens in the same understated fashion.

PTRC is the workhorse of the oil research and carbon capture and storage world, quietly getting things done, instigating new, important research programs, and ultimately being rewarded with the funding loyalty of industry and governments alike.

Dr. Patrick Jamieson

That's not to say credit isn't given where credit is due. In 08-09 the PTRC's work was featured on the front page of Regina's *Leader-Post*, covered on national radio and television newscasts, and even drew the attention of the new U.S. President Barack Obama on his visit to Canada in February 2009, who made mention of the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project as an example of international co-operation on reducing greenhouse gas emissions.

Under the stewardship of Carolyn Preston, in this fiscal year alone, the PTRC has secured an additional 20 million dollars in funding. Ten and a half million dollars was granted from the Canadian federal government to help establish a Business-Led Network of Centres of Excellence in Sustainable Technologies for Energy Production Systems (STEPS), a significant expansion of the existing Enhanced Oil Recovery program.

As well, Sustainable Technology Development Canada and the Saskatchewan Ministry of Environment's Go Green fund each awarded $5 million to the PTRC's Aquistore project to finance a research program that began in January of 2009. This exciting project will see CO_2 captured at the Consumers' Co-operative Refineries Limited's Regina refinery and injected into a nearby deep saline formation.

As the PTRC looks to its second decade, I would like to thank the staff of the PTRC for their commitment and hard work over the past year and the PTRC's key research partners for their high quality research work. May this second decade of research, development and deployment continue to provide a sustainable future for hydrocarbon resources in both Saskatchewan and Canada.

Pat Jamieson

Message from the Executive Director

Our Annual Report is sometimes a curious thing. While I'm always pleased to be able to show the world our ongoing research successes, more often than not I'm more excited to step into the future (as our title suggests) and speak to the vibrant coming years of both our province and our nation.

Dr. Carolyn K. Preston

The PTRC moved into a new realm of excellence and recognition in 2008-2009 with the establishment of our Sustainable Technologies for Energy Production Systems (STEPS) Business-Led Network of Centres of Excellence. This program – which greatly builds upon our existing Enhanced Oil Recovery program – will expand research into conventional oil and more-difficult-to-access hydrocarbon resources such as oil sands and oil shales. The additional $10.5 million in federal government funding over the next four years will be leveraged against new research dollars from both the province and the private sector.

Even as the PTRC is beginning to wind down two of our most successful research programs – the Joint Implementation of Vapour Extraction project (ending in 2010) and the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project (ending in 2011) – we are looking to the knowledge and consortium-building experience of these projects to develop two new, innovative programs.

The Aquistore project, which is looking into the safe storage of CO_2 in a deep saline formation, received an additional $5 million in funding from Saskatchewan's Go Green Fund to go with the $5 million announced last year by Sustainable Technology Development Canada. A research plan was initiated in January 2009, and the PTRC will bring to this project the extensive knowledge already gained from the Weyburn-Midale Project.

And what about the future of solvent-vapour extraction as a more environmentally sustainable method of heavy oil and bitumen recovery? The PTRC is entering a new research program with StatoilHydro to field test their innovative solvent-steam co-injection technology at their Alberta oil sands holdings. We were delighted to discover just as we went to press for this Annual Report that SDTC had again recognized the importance of PTRC's collaborative research, and granted $6 million to implement a comprehensive research program to accompany these field trials.

The PTRC is proud to be looking to the future and helping Canada attain energy self-sufficiency and environmental sustainability through technological innovation. I would personally like to thank our Board of Directors, provincial and federal funders, industry sponsors, research providers and, of course, my staff for making this past year such a success. Here's to the second decade of exciting cutting-edge hydrocarbon technology development in Saskatchewan!

Carolyn Preston

PTRC Organizational Chart and

Board of Directors

2008/2009 PTRC Board of Directors

Patrick Jamieson, Chair, Technology Advisor, Nexen Inc.

Lorraine Whale, Vice Chair, Research Consultant, Shell Canada Ltd.

Laurier Schramm, President & CEO, Saskatchewan Research Council

Malcolm Wilson, Director, Office of Energy and Environment, University of Regina

Dr. R.W. Mitchell, Independent Director

Kent Campbell, Deputy Minister, Saskatchewan Ministry of Energy and Resources

Brian Watt, Operations, Engineering Manager, Heavy Oil and Gas Business Unit, Husky Energy

David Payne, Vice President, Exploitation – East, Canadian Natural Resources Ltd.

John Zahary, President & CEO, Harvest Energy Trust

Dan Schiller, Vice President, Eastern Oil Business Unit, EnCana Corporation

Margaret McCuaig-Johnston (non-voting observer), Assistant Deputy Minister, Natural Resources Canada

Bill Jackson, Manager, Regulatory and Compliance - Public and Government Affairs, Apache Canada Ltd.

Mike Monea, Vice President of Integrated Carbon Capture and Sequestration Project, SaskPower

The PTRC Board of Directors as photographed in July, 2009 (some members will vary from 08-09).
Back left to right: Brian Watt, Dan Schiller, Francine Charron, Geoff Munro, Bill Jackson, Michael Monea, Ernie Pappas. **Front (seated in chairs):** Pat Jamieson, Carolyn Preston.
Missing from 08-09 board: Kent Campbell, Margaret McCuaig-Johnston, Robert Mitchell, David Payne, Laurier Schramm, Lorraine Whale, Malcolm Wilson, John Zahary.

Saskatchewan, the PTRC and the Future of Hydrocarbons in Canada

Saskatchewan's and Canada's

Energy Future

In the coming two or three years an interesting event could occur: the province of Saskatchewan will likely surpass Alberta to become the number one Canadian producer of oil from conventional sources. And while it's doubtful Saskatchewan will ever surpass the province to its west in total barrels per day – by virtue of Alberta's 375 billion barrels in proven oil sands reserves – the province known more for its crops and potash may yet make a name for itself internationally as a leader in conventional, affordable hydrocarbons.

That name is already in the making: in March 2009, a major news feature on both CCN's television network and website extolled Saskatchewan's resilience in the face of the global economic crisis. The province, noted CNN, sends more oil to the United States than does Kuwait.

The PTRC would like to think it has played a pivotal role in Saskatchewan's oil production reaching new highs – both for heavy oil, which predominates along the border with Alberta, and for conventional sources like the light and medium crudes in the province's southeastern corner. Working with such provincial institutions as the Universities of Regina and Saskatchewan, and the Saskatchewan Research Council, the PTRC has managed research programs that address most of the advances made in Canada's hydrocarbon industry over the last decade. From enhanced oil recovery technologies such as gas and water flooding, to CO_2 storage, to more environmentally friendly methods of in-situ oil sands recovery, the PTRC has helped boost oil production while striving to lessen environmental impacts.

Rising production of conventional oil from the rich Bakken formation promises to cement Saskatchewan's leading role (some estimates put this find at over 400 billion barrels, with perhaps one-quarter of this total lying beneath the province's south). This reality alone will mean the PTRC's research focus will continue to expand as the needs of industry and governments change. As you will read in this annual report, the PTRC's excellence in oil and environmental research has been recognized nationally and internationally over the past year, and its research program continues to expand to meet the challenges facing Saskatchewan, Canada, and the world.

From EOR to STEPS

PTRC is Awarded a Business-Led Network of Centres of Excellence

Since the PTRC's inception in 1998, enhanced oil recovery research has gone through a number of transitions. When the company was formed, such research was simply referred to as the "Core Research Program" since the primary reason the four founding partners (Saskatchewan Research Council, the University of Regina, Saskatchewan Energy and Resources and Natural Resources Canada) established the PTRC was to focus on Saskatchewan's unique, mostly heavy hydrocarbon resources, and to help establish and broaden the province's research and development capacity.

Mr. Ken Brown (new STEPS Network Manager)

As the PTRC became involved in other research projects – such as the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project – enhanced oil recovery research became delineated into specific research focus areas and amalgamated under a single title: the Enhanced Oil Recovery (EOR) program. Research directions for the EOR program were determined by a Technical Advisory Group, made up primarily of industry members, whose companies were also funding partners of the research, and government funders whose long-term view was focused on sustainable energy production.

Projects and focuses have changed over the years, from wellbore conformance control (see our 2001-2002 Annual Report) to cold-flow, foamy flow and related processes (see our 2003-2004 Annual Report). In 2008-2009, the EOR program had five principal areas of research and development, funded and approved by our industry and government partners and performed by our key research providers (Saskatchewan Research Council, University of Regina and University of Calgary):

1. Heavy Oil (Post) Cold Production
2. Enhanced Waterflooding
3. Solvent Vapour Extraction (SVX)
4. Gas Flooding (Miscible/Immiscible)
5. Improving Heavy Oil Predictability

In early 2008 the PTRC's Executive Director, Dr. Carolyn Preston, was encouraged by the Board of Directors to pursue application for funding through the Government of Canada's newly announced Business-Led Networks of Centres of Excellence (BL-NCE) program. But Dr. Preston felt that to achieve designation as a BL-NCE, the PTRC would have to broaden both the research direction and vision of the existing EOR program.

"I felt this new network should focus not just on heavy oil but on future hydrocarbon resources that are difficult to access and monetize," notes Dr. Preston. "If the future energy needs of Canada and the world are to be met in a timely and environmentally responsible way, we have to look at a whole array of hydrocarbon possibilities and processes."

Using the PTRC's own *Technology Roadmap for Saskatchewan, 2008 to 2050* as a starting point for the application, Dr. Preston developed a broader proposal for submission to the BL-NCE competition, proposing to establish the "Sustainable Technologies for Energy Production Systems" (STEPS) network. On one hand, the proposed network would focus on technology development that would help to lessen the environmental footprint of hydrocarbon extraction in Canada and the world. On the other, STEPS would expand research and development to include – aside from proven economic resources – emerging resources (such as inaccessible oil sands and shales), future resources (such as un-mineable coal seams) and synergies between different industries. STEPS would also be a leader in the development of the next generations of hydrocarbon researchers by expanding network members to include more universities and research partners.

Of the 40 applications, STEPS was chosen as one of ten finalists and, after a last presentation in Ottawa by Dr. Preston and three members of the PTRC's Board of Directors, STEPS was chosen in January 2009 as one of four inaugural Business-Led Networks of Centres of Excellence and awarded $10.5 million in funding over four years.

In 2008-2009 the PTRC began to unroll STEPS, transitioning the existing EOR program into the broader STEPS Network, initiating the development of a business plan and research strategy, and hiring Mr. Ken Brown (the former senior technical advisor in enhanced oil recovery at the Alberta Energy Research Institute) to be the network manager.

STEPS will strive to be the premier enhanced oil recovery research program in the world. In addition to the $10.5 million in federal funding from the NCE, the network will leverage more industry and other government money in order to provide some 50 million dollars in research and development funding between 2009 and 2013 to universities and research organizations across Canada.

As the PTRC begins its new decade, STEPS is positioned to help develop the next generation of hydrocarbon recovery technologies – to lessen the environmental footprint of development even as it improves the accessibility and security of Canada's energy supply.

Above: Professor Farshid Torabi observes the properties of fluids using the University of Regina's PVT (Pressure-Volume-Temperature) apparatus.

VISION

Improved hydrocarbon recovery with reduced environmental impact

MISSION

Accelerate the pace of energy technology RD&D for small-scale, low quality in-situ hydrocarbon deposits

GOAL

Ensure that Canada's heavy and extra-heavy oil production expands to keep pace with domestic and international demands, while developing the technological means to achieve this objective in a way that leaves the smallest possible environmental footprint

The PTRC gratefully acknowledges the Governments of Canada and Saskatchewan for their funding of the STEPS Business-Led Network of Centres of Excellence.

Heavy Oil (Post) Cold Production

Wormholes and Other Exotic Paths to Recovery

Wormholes have become a part of the lexicon of our culture – locations in science fiction movies where time and space bend, allowing safe passage through to another part of the universe or, better still, another dimension. The casual observer looking at the PTRC's post cold production research might be excused for thinking heavy oil field wormholes are a lot more mysterious than they are.

SRC's Dr. Norm Freitag works with principal research technologist Ray Exelby on a PVT apparatus.

In cold flow production – the predominant recovery method used in the Lloydminster area – sand is pumped to the surface with oil and water using progressive cavity (screw) pumps. It is a method that involves deliberately pumping unconsolidated reservoir sand up with the oil in order to increase production rates. This often leads to reservoirs that are riddled with "wormholes" or deep channels within the formation where oil can be accessed more effectively.

Wormholes are potentially the boon and the bane of the PTRC's post cold production research. In some post cold production processes, the proximity of the wormholes between an injection and production well may lead to the by-passing of the reservoir when water or a solvent is injected. But new technologies that employ horizontal wells, such as air injection and solvent vapour extraction, could see wormholes as an important tool.

"We have reason to believe that wormholes might offer solutions to the main operating problems of in-situ combustion," says Dr. Norm Freitag, a senior research scientist with the Saskatchewan Research Council and lead researcher on a project investigating air injection recovery. "It is possible, for example, to create a stable combustion front, to mobilize the oil and channel it to wormholes for recovery."

Dr. Koorosh Asghari of the University of Regina agrees about wormhole potential. He has been working on a modified solvent vapour extraction process that would treat reservoirs like a "black box" where wormholes do not necessarily need to be pinpointed for recovery rates to increase.

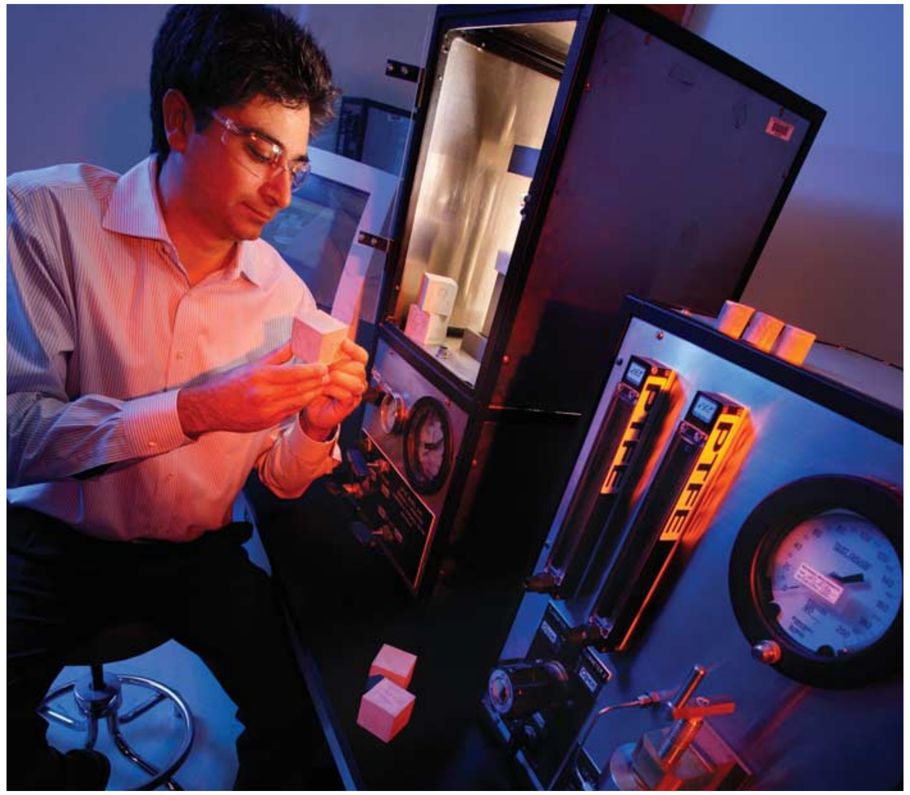
"One of the biggest challenges with reservoirs," notes Dr. Asghari, "is that it's not possible to determine the size or extent of the wormholes. A modified Vapex (solvent vapour) process aimed at evaluating and optimizing injection of hydrocarbon vapours into different locations in a wormholed formation should result in increased production."

Both researchers, along with SRC's Dr. Bernard Tremblay, are using scaled physical modelling and computer simulations to test new post cold recovery methods. One of Dr. Tremblay's projects involves cyclic solvent stimulation.

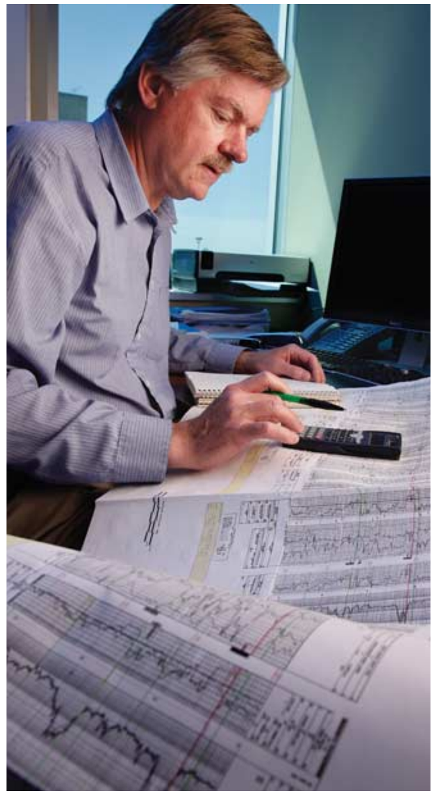
"Reservoir engineering is not an exact science," he notes. "Although we cannot predict exactly where wormholes develop, we can estimate their number and size based on previous laboratory and numerical simulations and on the oil, water, sand and gas production rates from the wells. As an engineer, my goal is to develop numerical simulation tools that can be used to estimate future oil production. A multi-well cold production model has, in fact, been developed at SRC as part of the PTRC consortium, and is being used to estimate numerically the optimum operating conditions for cyclic solvent recovery from cold-produced reservoirs."

However, the development of wormholes is only one piece of the puzzle. When the pressure in a virgin oil reservoir decreases below a certain level, methane dissolved in the oil comes out of solution in the form of bubbles which displace the oil towards the production well. Because heavy oil has a higher viscosity and contains more natural surfactants, the gas bubbles are more stable and can displace more oil before they coalesce. When this happens, gas predominantly flows out and leaves most of the oil behind. In order to model the cold flow process it is also important to measure the permeability to gas in laboratory experiments as was done by Dr. Tremblay in another PTRC- sponsored project.

With recovery rates in Saskatchewan's heavy oil reservoirs currently mired at between 7 and 10% of the 20 billion barrels of oil in place, the research in post cold flow technologies at the PTRC holds the promise of literally billions of barrels of oil for the province's, and the country's, future.



University of Regina's Professor Koorosh Asghari at work in his laboratory.



SRC's Dr. Bernard Tremblay examines well logs as input for his multi-well cold production model.

Saskatchewan Research Council (SRC) researcher Gay Renouf understands the intricacies and subtle characters of a whole lot of oil reservoirs.

Enhanced Waterflooding

Databases, Micro-models, and Developing New Technologies for Heavy and Unconventional Oil

As the manager of a PTRC-funded project compiling and comparing data on over 180 heavy and medium oil waterfloods in Saskatchewan and Alberta, Renouf is seeking to identify the parameters that optimize oil recovery over the life of a field.

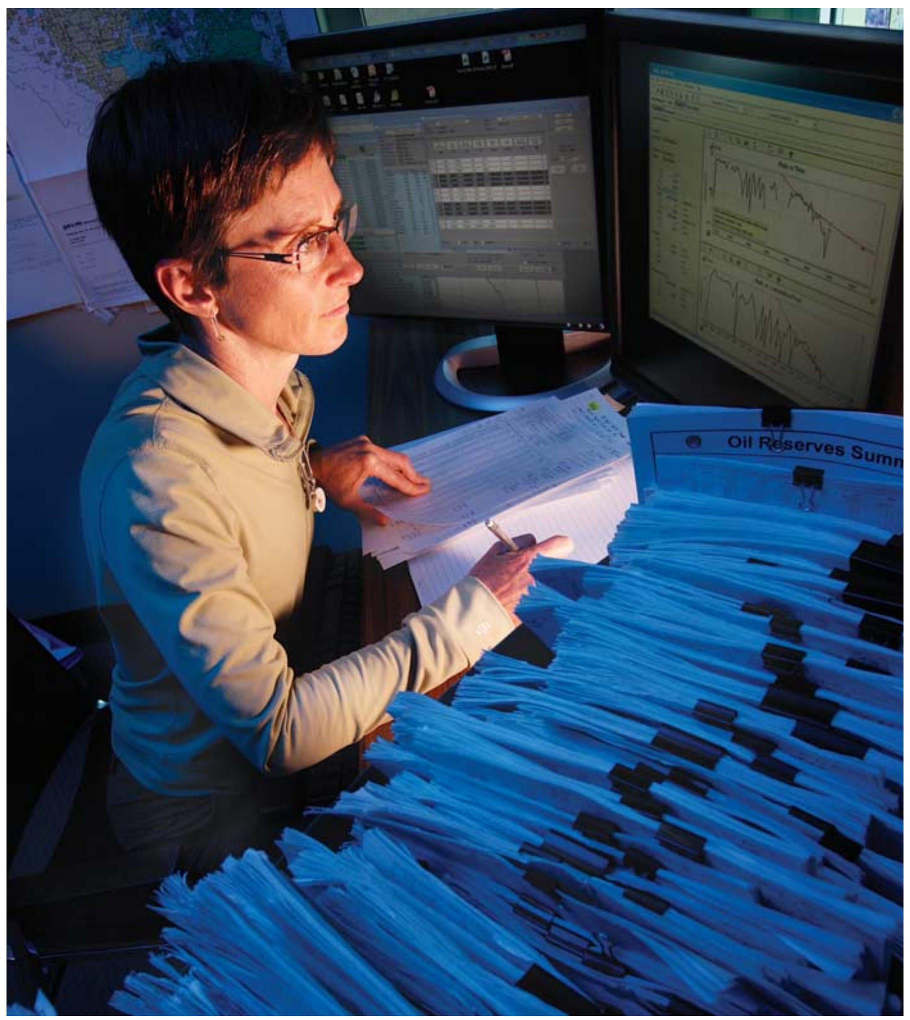
Waterflooding is the most common and oldest form of enhanced oil recovery for conventional and medium crude fields. The process, which involves injecting water (usually salty brines from saline aquifers) to sweep out partially depleted fields, was first used in the early 1900s. But the technology, which is being used with increasing frequency in heavy oil reservoirs, has different effects and inconsistent results when applied to those sorts of fields.

"Industry has been very enthusiastic in its response to this database," Renouf notes. "Because it includes medium and heavy oil waterfloods, the database results from the different reservoirs can be compared and we can see how one procedure or process might work over others."

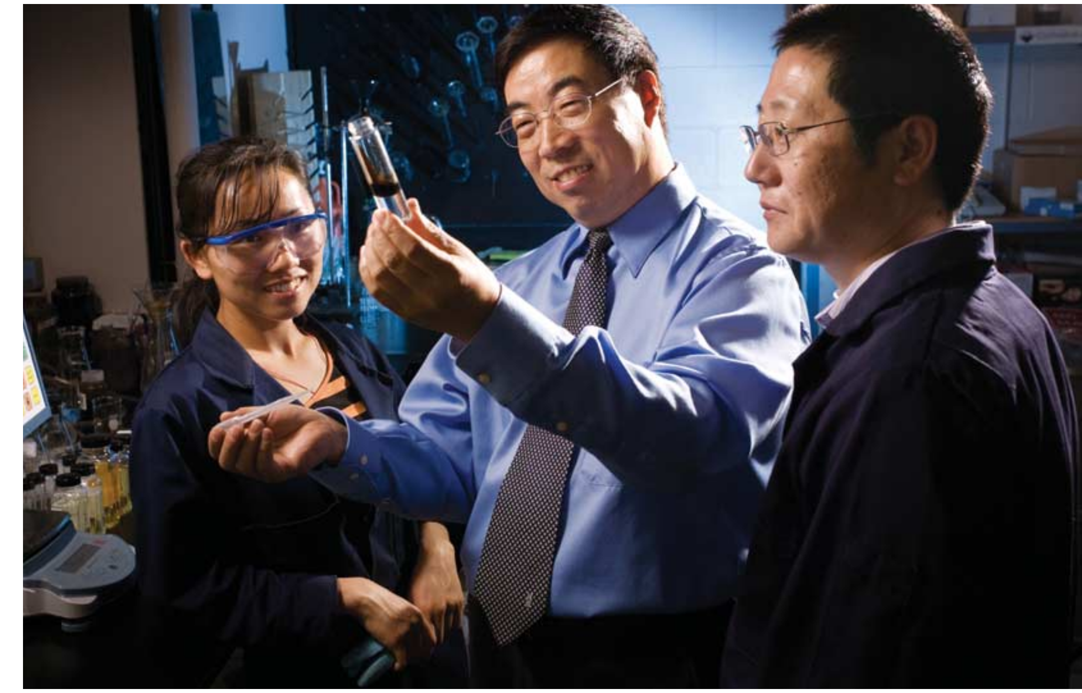
It's also possible to identify what reservoir factors and technologies have been the most significant at different points of time, in optimizing or undermining oil production.

"Some of the waterfloods in this database have been in operation for over fifty years. It is possible to determine what the best time is to do certain things, or to entertain certain technologies, or to perform certain activities."

It is precisely the identification of these optimal conditions in Renouf's database that potentially could feed into fellow SRC researcher Cindy Jackson's work – using micro-models of heavy oil reservoirs to see how water, oil and sometimes additives interact during a waterflood.



Gay Renouf's SRC office reflects her critical work on the waterflood database; the results have been enthusiastically supported by the PTRC's industry partners.



"We can see, for example, how the interaction between CO_2, water and oil occurs under specific conditions," notes Jackson.

Much of the fundamental information available about waterfloods comes from work done on conventional light and medium reservoirs. Such theoretical work often doesn't apply to heavy oil, the most common petroleum resource in Saskatchewan.

Jackson adds that Renouf's database "complements my work very well. If we can identify the fundamentals of interactions between brines and heavy oil, and use my micro-model to test different configurations, we can come to better understand the physical and chemical mechanisms that optimize heavy oil waterfloods, and apply those to the field."

The University of Calgary's Dr. Mingzhe Dong takes such models to the next level, simulating different techniques in waterfloods for enhanced heavy oil recovery to verify processes that will eventually be used in the field.

In his PTRC-funded project that seeks to simulate EOR chemical waterfloods, Dr. Dong uses the accumulated knowledge from his group's earlier research, including fundamental theories and models developed in other PTRC projects, and incorporates them into numerical reservoir simulations that are then used to design and predict oil field performance during chemical waterfloods.

"The flow of heavy oil in reservoir formations is a more complicated multiphase flow process than conventional oil flow," notes Dr. Dong. "Numerical simulation models need to be improved by incorporating the controlling mechanisms for specific processes in order to make meaningful predictions of the production performance."

Dr. Dong is examining the flow behavior of two types of emulsion (oil-in-water and water-in-oil) in porous sandpacks – an oil field feature that is prevalent in Saskatchewan heavy oil reservoirs in the Lloydminster area. Verification and improvement to his models will be achieved by history matching his simulated results with actual oil field data. ■

Above left: Cindy Jackson (SRC) views the etched glass micromodel used in fundamental studies of heavy oil waterfloods.

Above right: Professor Mingzhe Dong (University of Calgary) and doctoral students Haiyan Zhang (left) and Jinxun Wang (right) examine the interaction between a heavy oil and an alkaline solution by doing an emulsification test.

Solvent Vapour Extraction (svx)

Lessening the Environmental Impacts of Medium and Heavy Oil Production

Many of Saskatchewan's heavy oil reservoirs, which rest primarily along the border with Alberta, are notoriously difficult to access because of their thin pay zones – some as little as 3 to 8 metres thick – that result in excessive heat losses to the overburden and underburden rock during thermal recovery using methods such as steam-assisted gravity drainage (SAGD).

With the unique characteristics of these reservoirs, and with environmental concerns about water and energy use in thermal methods, the PTRC has been advancing solvent vapour extraction technologies as a more environmentally and economically sound method of increasing production from medium and heavy oil reservoirs.

SVX works by injecting gaseous solvents – such as butane, CO_2, methane and propane – into reservoirs to dilute the oil and drive it towards production wells. With the injection of such solvents, very little water and energy are consumed.

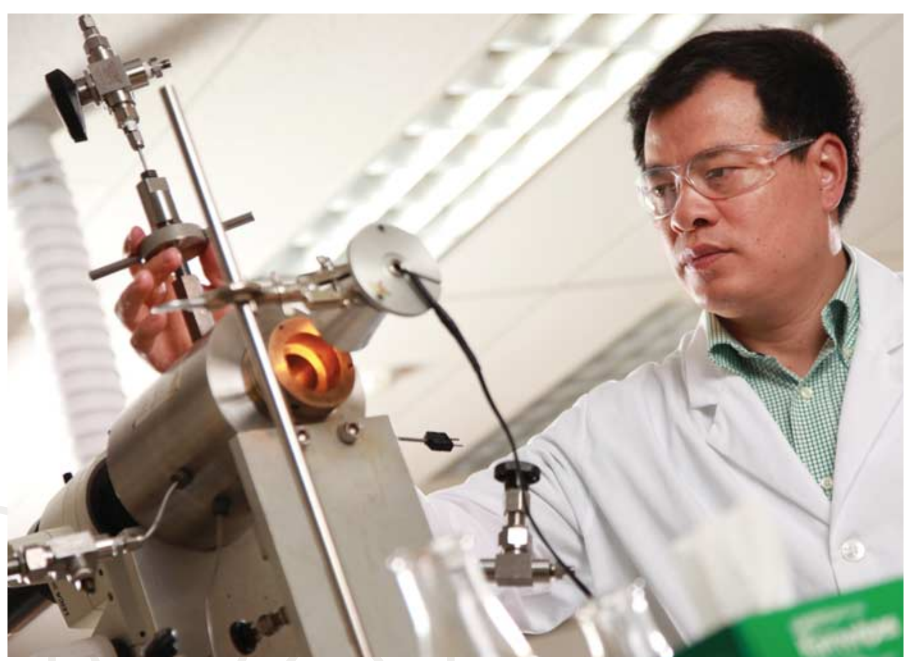
PTRC's SVX research program in 2008-2009 is driven by projects that investigate how heavy oil reservoirs react to solvent injection, in terms of the physical and chemical properties of the solvent-oil mixture during in-situ extraction, and the effects of such events as asphaltene precipitation and dispersion.

"Of course asphaltene precipitation has two effects, one beneficial and one detrimental," notes Dr. Peter Gu, petroleum engineering professor at the University of Regina, who directs different projects modeling and simulating the effects of solvent vapour extraction on oil reservoirs. "When asphaltenes precipitate, the result is usually a reduction in oil viscosity, which is certainly desirable. On the other hand, where pay zones and recovery pathways are restricted, reservoir plugging can occur."

Both Dr. Gu and the Saskatchewan Research Council's Kelly Knorr use computer numerical simulations and physical modelling to help investigate the optimal conditions for solvent injection into different kinds of reservoirs.

"We take data from the physical modelling," says Knorr, referring to SRC's state-of-the-art 3D physical model, "as well as lab PVT work and incorporate them into our computer simulations. Then we do a history match with our 3D physical result to help determine the best possible oil-solvent system for a field with particular characteristics."

With a widely varying array of heavy and medium oil reservoirs in Canada that might potentially benefit from SVX technology, the different research projects sponsored by the PTRC are helping to establish the best operating parameters for this sustainable recovery technology. ■

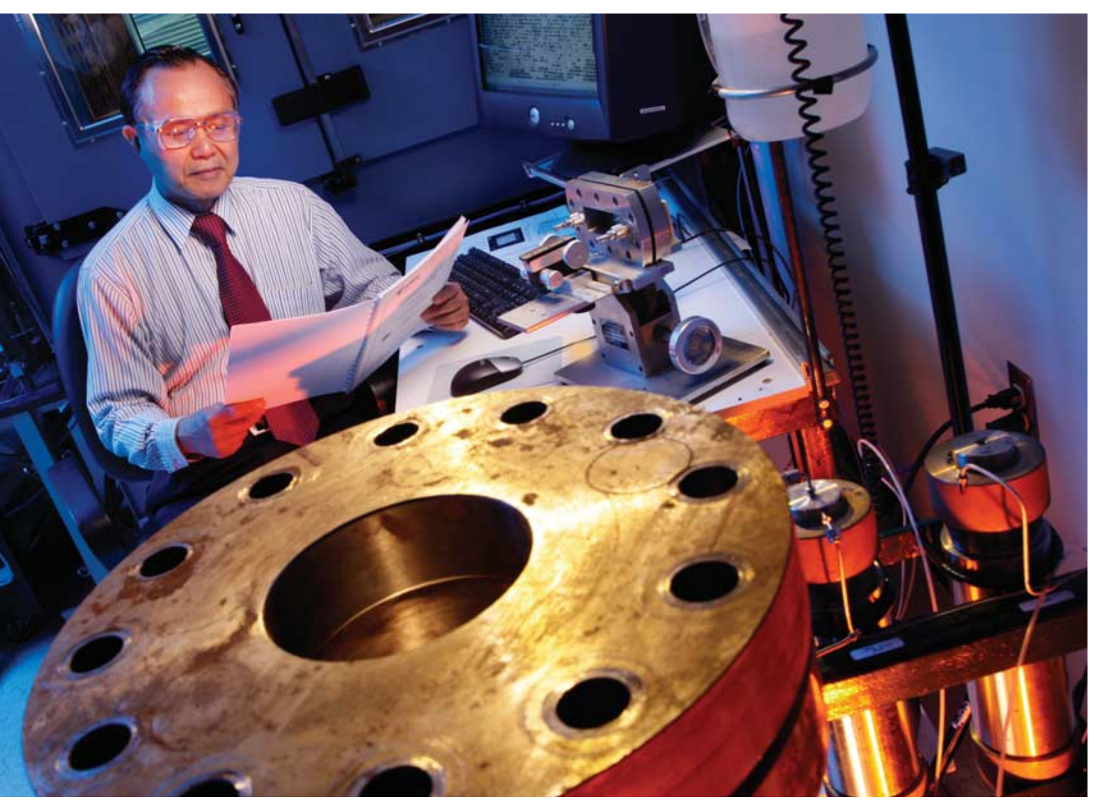


Professor Peter Gu works on the University of Regina's high-pressure liquid interfacial tension measurement apparatus.

Bart Schnell, Senior Research Technologist at SRC, works on the 3D physical model during SVX experiments.

Gas Flooding
(Miscible/Immiscible)
Optimizing Recovery while Improving the Economics of Gas Flooding

If waterflooding is the current workhorse of oil recovery in western Canada, gas flooding may be the future. The use of water to increase pressure and production in light, medium and heavy oil reservoirs will gradually become less effective but the addition of gases such as CO_2, methane and propane offers the potential to increase recovery factors – sometimes by as much as 20 percent – over waterfloods alone. Unlike light oil, however, heavy oil poses unique challenges to gas flooding, both economic and technological, that the PTRC's research is meeting head on.



Dr. Sam Huang and Dr. Mars Luo – both of the Saskatchewan Research Council – manage two of the most important PTRC projects examining gas floods. The first looks at simulating the optimal CO_2-solvent properties in immiscible gas floods to increase the mixing of heavy oil and solvent, thus reducing oil viscosity and allowing more of it to be recovered during accompanying waterfloods.

"Gas flooding is certainly more costly than straight waterflooding," says Dr. Luo, noting the cost of solvents such as CO_2, flue gas, butane and propane. "But with many of the heavy oil fields in the Lloydminster area reaching the end of their abilities to produce with waterfloods alone, and with pay zones too thin to rely on thermal recovery methods like SAGD, optimizing gas solvents is essential."

The second project, rather than simply addressing gas properties, is looking at the coupling of gas injection with water while making the latter thicker and more viscous by adding polymers to the mix. Thicker water will be more efficient when sweeping out the solvent-oil mixture.

"CO_2 is one of the most common gases used to enhance oil recovery," notes Dr. Huang, discussing the coupling of gas injection with polymers. "In most cases, CO_2 alone can increase reservoir production by as much as 10 to 12 percent. But if you combine polymer/water injection with CO_2, our study has indicated you could increase production by as much as 20 percent."

2008-09 saw successful data generated to interest companies in possible field application of these technologies. Subsequent research will look into solvent/gas recovery, since commercial viability is dependent on recycling the more expensive solvents rather than losing them to the reservoir.

SRC's Dr. Sam Huang, Manager of Enhanced Recovery Technologies, beside a micro-model for the study of microscopic displacement behaviour of CO_2 and oil.

Left: Dr. Mars Luo and SRC research technologist Kevin Rispler examine samples from the radial core flood apparatus.

Above: Professor Tony Yang, of the University of Regina, monitors core flooding equipment in the lab.

The unique geology of a reservoir also affects the way gases work when they are injected. The University of Regina's Dr. Tony Yang – who is investigating the optimization of CO_2 flooding – is constructing theoretical models and simulations to help minimize uncertainties during CO_2 floods.

"When we do a simulation using a computer, we history match with existing reservoir geologies. We develop different geological models with good history matching, as well, and test their responses to CO_2 flooding."

Perhaps the most famous CO_2 flood in the world is the EnCana Weyburn field (the focus of the PTRC's Weyburn-Midale CO_2 Monitoring and Storage Project), but CO_2 injection has been used as a method in enhanced oil recovery for decades, principally in North America. Dr. Yang's simulation and modeling research improvements could see potential application to many fields around the world.

"When you combine simulations with production histories," he notes, "the results give you a better picture of the best possible gas injection and production strategies to use."

JIVE Research Enters Its Final Year

As conventional oil production continues to decline in western Canada, being replaced with less easily accessible resources such as heavy oil and oil sands, technological and environmental challenges continue to increase. Current technologies for extracting these unconventional resources remain expensive and energy intensive – such as the most common form of in-situ oil sands extraction, steam-assisted gravity drainage (SAGD).

SAGD requires sources of both water and heat to produce the steam needed to extract heavy oil and oil sands from deep in underground formations. Natural gas is the most common energy source and water use may be up to four barrels per barrel of oil produced during extraction. Some studies, including the Alberta Chamber of Resources' *Oil Sands Technology Road Map*, have estimated that up to 70% of Canada's natural gas supply could end up being used in SAGD and other in-situ oil sands operations by 2020. This is simply not sustainable.

Solvent vapour extraction technology is an enhanced oil recovery process that involves injecting a gaseous hydrocarbon – usually butane or propane – into a heavy oil reservoir. The solvent mixes with and diffuses into the heavy oil to reduce its viscosity and make it flow more easily. The potential advantages of such a technology, over SAGD and other thermal processes, are the virtual elimination of water use and significant reductions in energy requirements, with a corresponding reduction in natural gas use. As well, with only 8% of heavy oil currently recoverable from reservoirs using existing technologies, solvent vapour extraction offers the potential of raising this figure to as high as 20%. In Saskatchewan alone this could mean another 4 billion barrels of recovered heavy oil.

In 2005, the PTRC began the JIVE project – Joint Implementation of Vapour Extraction – involving a vigorous laboratory testing program alongside three field trials of solvent vapour extraction technologies at three heavy oil field locations along the Saskatchewan-Alberta border. These field trials have been unique in their use of dual solvents–one for pressure drive in the resevoirs (methane) and one for viscosity reduction (propane or butane).

Public sector funders of the research include Sustainable Development Technology Canada, which awarded $3.2 million over four years, Saskatchewan Energy and Resources and Natural Resources Canada through the Technology Early Action Measures (TEAM) program. The primary industry partners – Nexen Inc., Husky Energy and Canadian Natural Resources Ltd. – have each provided funding and in-kind support through testing of different solvent vapour combinations in field pilot studies.

"The field pilots have provided invaluable information on the formation of asphaltenes and solvent recovery," notes Kyle Worth, the PTRC's manager of JIVE. "One of the major challenges is the ability to understand the mechanisms involved to effectively recover solvent. Solvents like methane, propane and butane are expensive, so recovery is important."

Successful oil and solvent recovery often depends on the unique characteristics of each reservoir and the adaptation and modifications of solvent combinations and operating parameters to match those differences.

"Initial results are promising," says Worth. "The data provided by the three pilots will be the basis for an economic analysis to be completed next year."

The majority of the research accompanying JIVE is being conducted by the Saskatchewan Research Council (SRC) and the Alberta Research Council (ARC), with some additional testing from the private sector. Brian Kristoff is a manager of enhanced oil recovery field development with SRC's Energy Division, including the JIVE research being conducted there.

"Our advanced 3D scaled physical model has been critical in helping to simulate the conditions that are being encountered in the different companies' field trials," he notes. "One of our ultimate goals is to provide a better predictive modeling tool for the field application of solvent vapour extraction technologies."

Ron Sawatzky, a reservoir engineering team leader with the Heavy Oil and Oil Sands business unit at the Alberta Research Council, notes that ARC has been continuously engaged in applied research focused on the development and implementation of solvent-based processes for western Canadian heavy oil reservoirs since the early 1990s. ARC believes that JIVE offers a novel collaborative approach between government, industry and research organizations that allows the testing of enhanced heavy oil recovery technologies to move forward more rapidly from the laboratory-scale stage to the field-scale stage.

The project enters its final year of research in 2009-2010.

The Husky Edam solvent injection/production facilities, east of Lloydminster, Saskatchewan.

(Photo courtesy of Husky Energy)

08 09 the next 10 Years

Weyburn-Midale Receives International Attention

The Obama Factor

IEA GHG Weyburn Midale CO_2 Monitoring & Storage

The most well-known of the PTRC's research projects is the International Energy Agency Greenhouse Gas R&D Programme's Weyburn-Midale CO_2 Monitoring and Storage Project, and in February 2009 the project received an unexpected bump in media attention. At the first meeting in Ottawa between Prime Minister Stephen Harper and the new President of the United States, Barack Obama, the "North Dakota-Weyburn Project" was cited as one of the best examples of cross-border co-operation on environmental technology development.

Within 24 hours the PTRC's phones were ringing off the hook, with both American and Canadian journalists requesting interviews. The PTRC's Executive Director, Dr. Carolyn Preston, appeared on CBC Newsworld to explain the project, and Dr. Steve Whittaker, PTRC's senior project manager, continues to field requests from magazines, television networks, and newspapers.

Since 2000, the Weyburn-Midale Project has seen scientists from over 30 different universities and research organizations contribute towards monitoring and verification of CO_2 being injected into EnCana's Weyburn and Apache's Midale oil fields in southeastern Saskatchewan. The CO_2 – which is pipelined 320 kilometres from the Dakota Gasification Company's Great Plain's Synfuels Plant in North Dakota – is used in combination with waterflooding to enhance oil production in both fields. The carbon dioxide remains in place, with any produced CO_2 being separated from the oil at the surface to be recycled and re-injected with the approximately 8000 tonnes that arrive daily from North Dakota.

The research project, now in its final phase, will be completed in 2011; in 2008-2009, progress was seen in four principal research areas: site characterization, wellbore integrity, monitoring and verification (including geomechanical and geochemical techniques) and risk assessment.

"2008-2009 was a pivotal year for Weyburn-Midale, and there are currently 23 active technical projects underway," notes Dr. Steve Whittaker. "All are crucial to our final goal of producing a best practices manual that will highlight for other CO_2-enhanced oil recovery operations what is required to safely transition into long-term storage."

Active projects that began this past fiscal year include an examination of caprock integrity; chemical interactions that occur between CO_2, brine and rock; and stochastic modeling to optimize the agreement between observed and predicted CO_2 storage performance.

During 2008-2009, Weyburn-Midale surpassed StatoilHydro's Sleipner project in the North Sea as the largest CO_2 storage project in the world, with over 14 million tonnes currently underground, and more than 2 million tonnes added annually. The project enters its final year of research in 2010-2011. ■

Above left:

A worker walks through EnCana's main plant at Weyburn. Visible in this picture are the compressor's dehydrators and coolers.

(photo courtesy of EnCana)

The IEA GHG Weyburn-Midale Monitoring and Storage Project is funded by the following groups:

Industry:

Apache
Aramco Services
Chevron
Dakota Gasification
EnCana
Nexen
OMV Austria
SaskPower
Schlumberger
Shell

Government:

Alberta Energy Research Institute
IEA GHG R&D Programme
Natural Resources Canada
Research Institute of Innovative Technology for the Earth (Japan)
Saskatchewan Ministry of Energy and Resources
United States Department of Energy

The Way Forward

Three new research projects for the PTRC

Aquistore: CO_2 Storage in a Deep Saline Formation

Over the past ten years, the PTRC has garnered a wealth of knowledge and expertise in the area of CO_2 geological storage through its management of the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project. However, depleted oil fields, such as those involved in the Weyburn-Midale project, are just one potential location for the sequestering of CO_2. The International Panel on Climate Change has estimated that a far larger storage potential exists in deep saline formations, which are located in the earth at levels up to several thousand metres deep.

Saline formations naturally contain brine in minute pores into which CO_2 may be injected, dissolved, effectively trapped and securely stored in the rock thousands of metres underground.

Aquistore, the PTRC's newest CO_2 storage project, will investigate the potential of storing CO_2 in a deep saline formation. Aquistore incorporates the capture of CO_2 from the Consumers' Co-operative Refinery Limited's (CCRL) Regina Refinery, transport to a nearby injection site, and storage in a deep saline formation at a depth of over two kilometres.

Aquistore is a 100 million dollar project, including a significant financial commitment by CCRL to capture the CO_2. On the research side, the Saskatchewan Ministry of Environment's Go Green Fund and Sustainable Development Technology Canada (SDTC) have each contributed five million dollars. Aside from CCRL, industry partners include Schlumberger, Enbridge, SaskEnergy, and SaskPower.

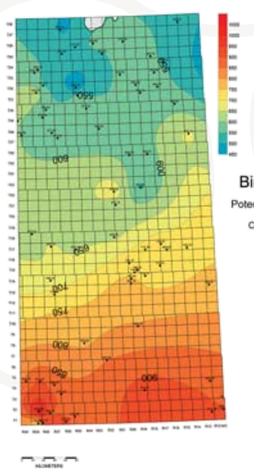
Aquistore – which has already made significant progress towards site selection for injection of the CO_2 – will include an extensive research component including: site characterization; facilities integration; injection well design; measurement, monitoring and verification; public communications and outreach; and economic and engineering assessments.

PTRC has engaged leading scientific experts in geological carbon storage-related research to develop and continually assess research focused on site characterization, field and laboratory studies, numerical simulations, CO_2 monitoring programs and risk assessment. The project is expected to run until 2013. ■

The CCRL Regina refinery will capture the CO_2.

(shown with permission of the Consumers' Co-operative Refineries Limited)

Saskatchewan Phanerozoic Fluids and Petroleum Systems Assessment



This map showing the potentiometric surface of the Devonian Birdbear formation in southwestern Saskatchewan is part of a project to examine fluids in the Saskatchewan subsurface and their influence on petroleum generation and migration.

As the recent discovery of the Bakken formation attests, Saskatchewan's rich hydrocarbon resources can sometimes show up in locations that are unusual or unexpected and there are still significant hydrocarbon discoveries to be made in the province.

In January 2009, the PTRC received one million dollars in funding from the Government of Saskatchewan to undertake a study of "Saskatchewan's Phanerozoic Fluids and Petroleum Systems." The project is examining how hydrocarbons and other basinal fluids in the Saskatchewan subsurface have evolved and migrated over geologic time to better understand controls on where petroleum fluids are most likely to have ended up in the present day.

This five-year project, which began spring 2009, involves the University of Regina, University of Alberta, and geoscientists in the Saskatchewan Ministry of Energy and Resources' Department of Exploration and Geological Services.

Aspects of the study include completing hydrogeological mapping of Saskatchewan's subsurface, filling gaps in the southwestern and northwestern parts of the province. State-of-the-art software will incorporate these data to construct 3D models describing the maturation, generation and migration of petroleum into, and within, Saskatchewan.

Principal Investigators include Dr. Stephen Bend of the University of Regina and Dr. Ben Rostron of the University of Alberta. Five graduate students will also be funded – adding capacity to the petroleum geosciences program at these universities. This project continues PTRC's role in building petroleum research capabilities, seen as critical to the future of an energy-secure Canada.

SOLVE: A More Environmentally Friendly In-situ Oil Sands Process

StatoilHydro's Leismer field operations southeast of Fort McMurray. *(photo courtesy of StatoilHydro)*

In late summer 2009, the PTRC was excited to learn that its joint research program with StatoilHydro to investigate ways of mitigating CO_2 emissions and water use in oil sands operations was awarded 6 million dollars in funding from Sustainable Technology Development Canada.

The Steam-Solvent Co-Injection Project (SOLVE) aims to develop, optimize, and commercialize technology that combines steam-assisted gravity drainage (SAGD) with solvent injection. A pilot of StatoilHydro's new solvent-steam process will be implemented in part of the Leismer field in Alberta to optimize the process for possible application across the entire field and to assess the reduction in environmental impacts during production by this method.

The PTRC – through an accompanying research program in development – will contribute towards optimizing the technology.

Key milestones include drilling co-injection well pairs at the demo site (completed in 2009), injection of steam in early 2010, and co-injection of solvent beginning in autumn 2011. Pilot modeling and simulations are already underway, and data collection, monitoring and measurement will continue throughout the project.

EOR Research Summaries

The following project descriptions are snapshots, at March 31, 2009, of the work being carried out in the PTRC's Enhanced Oil Recovery Program.

Heavy Oil (Post) Cold Flow

Gas Relative Permeability Measurements for Solution Gas Drive (Year 2)

Three solution gas drive experiments were performed in a cylindrical sandpack, with the production direction varied to be vertical downwards, vertical upwards or horizontal. Results showed that the gas relative permeability in the vertical upwards direction was two orders of magnitude lower than in the opposite direction. This suggests that using uniform gas relative permeability curves in numerical simulations may lead to an over-estimate of the vertical gas migration and thus to inaccuracies in oil recovery predictions. Project Leader: Bernard Tremblay (SRC)

Multi-Well Cold Flow Model

This project's aim is to advance a multi-well numerical model to estimate optimum well spacing and infill scheduling for cold production. The model was used to estimate the potential for infilling seven 40-acre-spacing cold flow wells operated by Devon Canada, based on the oil, sand, water and gas production from each well. The model predicted that the region between the wells was too depleted to be economically recovered with infill wells. A method was explored to estimate the extent of the wormhole channel network for post-cold production enhanced oil recovery (EOR) processes, based on gas injectivity tests. Project Leader: Bernard Tremblay (SRC)

Air Injection Pilot Preparation (Year 2)

This multi-year project is devoted to a new air-injection process for heavy oil fields that have matured under cold production. In 2008-09, the economic recession hampered one of the two main goals, the establishment of a producer consortium to implement a field pilot. However, significant progress was made towards the accompanying goal of reliable simulation methods for air injection. The highlight was the first-time use of a new multi-well simulation model to predict effects of wormholes on air-injection and oil production behaviours. Project Leader: Norm Freitag (SRC)

Scaled Physical Model of Post-Cold Production

A scaled experiment simulating cyclic solvent injection into a single well after cold production showed that the oil recovery for each cycle depended strongly on the free gas saturation in the sandpack after the injection stage. Recovery was greater by far in the two cycles in which the sandpack was saturated with live oil, with no free gas saturation. It is recommended to closely monitor the solvent injection pressure in the field until a plateau is reached and to use a rich solvent to completely fill any previously developed free-gas channels. Project Leader: Bernard Tremblay (SRC)

Modeling and Simulation of Isothermal/Non-isothermal Combustion Experiments

Can the kinetics parameters obtained for heavy oils be extended to other oils, especially medium and light crudes? If so, exhaustive tests on individual oil reservoirs would not be needed prior to developing proper recovery methods. The combustion kinetics of a previously unexamined medium oil were studied. Initial results indicate that the combustion category of reaction rates is not transferable between reservoirs. In addition, a new approach — a distributed activation energy model — was tested to determine how well it could describe the asphaltene pyrolysis kinetics for this oil. Project Leader: Nader Mahinpey (U of R)

Cold Flow Production Database

Which reservoir parameters and production practices affect the success of cold production rates, and to what extent? Data from well logs, reservoir parameters, and operating factors were gathered from 11 western Canadian oil pools to determine which factors best correlated with cold production success. Multivariate analysis was used to assess the parameters that optimize cold-flow and post-cold-flow production. Project Leader: Gay Renouf (SRC)

Modified Vapex for Wormhole Reservoirs

This project was aimed at evaluating various schemes for injecting CO_2 and hydrocarbon vapour solvents into wormhole reservoirs in order to improve oil recovery from these fields. A comprehensive set of simulation runs was completed for over 50 different injection scenarios, and additional experiments were conducted to determine the diffusion coefficients of these simulations, which will be essential for potential application of the solvent vapour extraction process. Project Leader: Koorosh Asghari (U of R)

Enhanced Waterflooding

Improved Waterflooding of Heavy Oil

The application of waterflooding to heavy oils, although common in western Canada, relies largely on operator experience and on the theory for light and medium oils. Better understanding of how heavy oil waterflooding differs from that of its lighter counterparts could help to ensure the success and optimize performance of the process. In micro-model waterfloods, SRC viewed the formation of water-in-oil emulsions under high shear forces and of oil-in-water emulsions as oil was dragged by water. We observed changes of the matrix wettability that affected oil/brine behaviour and increased recovery. Two enhanced oil recovery methods, CO_2 (gas)-assisted waterflooding and alkaline flooding, improved recovery. Project Leaders: Cindy Jackson (SRC), Koorosh Asghari (U of R)

Improving Conformance Control Technologies – Application to Heavy Oil Reservoirs

Conformance control treatments using polymers and polymer gels can improve production in a variety of conventional and heavy oil reservoirs. Work focused on select polymer/brine systems and the relationship of viscosity with polymer concentration and with shear rate. Dynamic adsorption tests of polymer/brine/sand systems yielded a higher adsorption value than did static adsorption tests due to additional non-adsorptive mechanisms. Polymer gels placed in unconsolidated sands were shown to effectively reduce permeability to brine down to essentially the low value of the gel. Permeability to oil was found to be disproportionately higher. A dual-permeability coreflood illustrated the importance of gel volume and minimizing crosslinker loss. Project Leader: Ryan Wilton (SRC)

Low Cost Chemicals for Enhanced Waterflooding

This project advanced an economical and efficient smelt clean-up process to provide a low-cost alkali for alkaline-surfactant-polymer floods of heavy oil. Smelt, a pulp mill residue available for the cost of transportation, can contain over 60% sodium carbonate (Na_2CO_3), along with other, undesirable, chemicals. We tested the performance of the smelt-derived alkali in micromodel floods and observed a significant change in the displacement pattern: formation of water-in-oil emulsion and wettability alteration that increased oil recovery considerably and proved the potential of alkaline flood processes for heavy oil recovery. Project Leaders: Cindy Jackson, Petro Nakutnyy (SRC)

Success of Heavy Oil Waterfloods – Factors and Predictions, Phase II

This statistical study of 176 western Canadian heavy and medium oil waterfloods examined how their success varied under different flow regimes (that occur as the waterflood ages): (I) oil only, (II) mostly oil, (III) water-in-oil emulsions, and (IV) water dragging clumps of emulsions. The most successful medium oil waterfloods fared best in Regime III, but 69% of the heavy oil waterfloods fared best in Regime IV and were the more successful of this category overall. Waterfloods operating at high water/oil ratios for many years were found to be quite successful. Other operating parameters examined included preproduction, periods of underinjection, injection water quality, and horizontal well configuration. Project Leader: Gay Renouf (SRC)

Dispersion-Alternating-Displacement Technique for Heavy Oil Recovery by Alkaline Flooding (Year 3)

In this newly developed alkaline flooding process, in-situ water-in-oil (w/o) dispersion can effectively increase water-flow resistance in water channels to improve sweep efficiency, and in-situ oil-in-water (o/w) emulsions use water to entrain and displace heavy oil out of oil sands. This project produced the following results for two target heavy oils: 1) chemical formulas for improving sweep efficiency and enhanced oil recovery by chemical flooding, 2) a method to treat divalent ions of the injection water for field application, and 3) a method of treating produced oil-in-water emulsions. Project Leader: Mingzhe Dong (U of C)

Simulation of Enhanced Heavy Oil Recovery (EHOR) by Chemical Flooding (Year 3)

The mechanisms of two-phase (oil and water) flow in chemical injection for EHOR were studied. The project incorporated developed fundamental theories and models into numerical reservoir simulation for designing and predicting the field performance of enhanced waterfloods. Numerical simulations were conducted to match the production histories of six sandpack flood tests. The simulated oil production and pressure drop curves fairly matched the test results. Field scale numerical simulations were performed on a rectangular area 450 m long and 400 m wide with a pay thickness of 4.5 m. These simulations showed promising results for chemical flooding for heavy oils. Project Leader: Mingzhe Dong (U of C)

Waterflood Additives for Improved Heavy Oil Recovery (Year 2)

This project's goal is to develop enhanced waterflooding technologies for heavy oils utilizing interfacial instability by alkali-surfactant (AS) and mobility improvement by polymer (P). Several different additive formulas were tested. An AS flood recovered only 0.71% incremental original oil in place (OOIP), but the enhanced recoveries from a polymer flood and a polymer-assisted AS flood were 10.26% OOIP and 14.65% OOIP, respectively. There is a limit of polymer concentration above which tertiary oil recovery varies almost negligibly. These results suggest that mobility control by polymer is extremely important for effective recovery of viscous heavy oils. Synergic effects from the different ASP additives maximized the performance of these processes. Project Leaders: Patrick Zhang, Mars Luo (SRC)

Solvent Vapour Extraction (SVX)

Evaluation of SVX Processes Using a 3D Physical Model (Year 1)

An attractive alternative to thermal recovery methods, SVX uses less energy and water; avoids CO_2 production; and is more suitable for thinner, partially depleted reservoirs. One SVX experiment was run on SRC's 2.5-m-thick 3D scaled physical model; results were compared with previous ones to evaluate the effects of well type and well pattern spacing on oil production rates and recoveries. The solvent chamber(s) were thermally imaged during solvent injection and blowdown phases, and confirmed from the excavated models. The oil, water and gas rates and recoveries were scaled to field dimensions using an implicit dispersion flow model and scaling method. Using previous laboratory data, extensive numerical simulation was performed to develop a tuned field prediction model. Advanced simulation methods were used to correct both the laboratory and field models for excess dispersion. Project Leader: Kelly Knorr (SRC)

Asphaltene Precipitation and its Effects on the Vapex Heavy Oil Recovery Process

In 2008-09, the project involved a series of pressure-volume-temperature (PVT) and fluid phase behaviour studies of heavy oil-solvent systems. We successfully characterized the heavy oil-propane system in the presence or absence of asphaltenes and the C_3-precipitated asphaltenes during several Vapex tests. The results revealed that among the most important factors in success are the operating pressure, reservoir permeability, solvent type, and oil composition. Project Leader: Peter Gu (U of R)

Application of Horizontal Well Testing in Heavy Oil Reservoirs for Estimating Chamber Size for Vapex and SAGD Processes (Year 2)

A theoretical/numerical model for predicting the pressure distribution in the reservoir using a horizontal well was developed. As well, a new analytical solution (empirical equation) was developed and used to calculate the chamber volume for steam-assisted gravity drainage. The results were correlated with CMG simulators and gave accuracy up to 90%. The model for predicting the chamber size for Vapex process is still under research. Project Leader: Ezeddin Shirif (U of R)

Phase Separation of a Solvent-Saturated Heavy Oil During Solvent-Based Heavy Oil Recovery Process

This project quantified the detailed effects of phase separation on the physical and chemical properties of a solvent-saturated heavy oil, which were then used to develop a theoretical model of phase behaviour under various conditions. The obtained experimental data and empirical correlations can greatly help the petroleum industry to design and optimize solvent-based heavy oil recovery processes. Project Leader: Peter Gu (U of R)

Solvent Dispersion Effect on the Vapex Heavy Oil Recovery Process

Several Vapex physical modelling tests were conducted with different solvent dispersion effects. A few existing mathematical solvent dispersion models were studied and an optimum such model was identified as best suited for the Vapex heavy oil recovery process. With these physical modelling data, an analytical model has been derived to simulate the evolution process and spreading velocity of the solvent chamber and predict the cumulative heavy oil production in the entire Vapex process. Project Leader: Peter Gu (U of R)

Underground Sonar for Detecting the Growth of the Vapex Chamber in the Vapex Process

This project aims at utilizing acoustic sonar for detecting the shape of the vapour chamber in Vapex processes. An experimental setup was designed and installed at the PTRC laboratories. To date, the shape and size of a chamber of dry sand have been measured in an environment of water-saturated sand. Special digital signal processing algorithms have been developed and tested for this purpose. Currently, experiments in an oil environment are underway. Project Leaders: Koorosh Asghari, Raman Paranjape (U of R)

Gas Flooding (Miscible/Immiscible)

Coupling Gas and Polymer Injection (Year 2)

This aim of this work is to optimize a new EOR process for heavy oil: coupled CO_2 and polymer injection, or polymer-gas-alternating water (PGAW). Physical properties of reservoir fluid–CO_2-enriched flue gas mixtures were measured; and five corefloods were run to evaluate different injection schemes. The coreflood results showed that: 1) CO_2 had better recovery performance than CO_2-enriched flue gas; 2) with a lower polymer concentration, differential pressure decreased, but so did oil recovery; and 3) an optimal injection scheme with a lower polymer concentration and lower gas injection rate improved recovery by PGAW. Project Leaders: Patrick Zhang, Mars Luo (SRC)

Optimal Solvent Properties to Create Maximum Efficiency in Miscible Gas Flood for Heavy Oil Recovery

The goal of this research is to determine the most suitable solvent for recovering heavy oil in immiscible gas floods. The phase behaviour and physical properties of a heavy oil with three different solvents (CO_2, 19 mol% C_3H_8 in CO_2, and CO_2-enriched flue gas) were determined. Five linear and two radial coreflood tests were conducted using the first two solvents at different operating pressures. The results showed that the C_3-CO_2 mixture had the highest solubility in the oil and provided the greatest oil viscosity reduction. This mixture thus led to much higher enhanced oil recovery than with CO_2 alone; and gas utilization was significantly reduced. Project Leaders: Patrick Zhang, Mars Luo (SRC)

Integrated Optimization of Displacement Efficiency in a CO_2-Flooded Reservoir under Uncertainty

The objectives of this project are to provide a pragmatic approach and theoretical models for optimizing performance in a CO_2 EOR process under uncertainty. A hybrid technique was developed to accurately determine and model fluid saturation and distribution in hydrocarbon reservoirs, while a novel technique was developed to dynamically update the geological model in real time and to achieve multiple solutions for history matching. As well, a pragmatic approach and theoretical models were developed for optimizing reservoir performance in a CO_2 EOR process with consideration of both physical and financial uncertainty. Project Leader: Tony Yang (U of R)

Improving Heavy Oil Predictability

Equation-of-State Characterization of Heavy Oils

The conventional correlations of the physical properties of oils, based mainly on light-oil data, generally become more inaccurate when heavier oils are considered. This project addresses the overall need to provide reliable heavy-oil correlation methods that can be trusted during numerical simulations. The approach this year was to review recently proposed methods and test/improve them. Last year, a new and unique isothermal data set on heavy oil fractions was obtained. A very recent approach to correlating equilibrium phase properties showed good promise when tested against these data. Project Leader: Norm Freitag (SRC)

PVT and Viscosity Modeling of Gas and Liquid Diluted Heavy Oils

A new effective tuning procedure was developed and used to predict the viscosity for oils of all density ranges and for pressures above and below the saturation pressure based on the friction theory model. The solubility of CO_2 was measured in a Lloydminster oil and its SARA (saturates-aromatics-resins-asphaltenes) fractions. Experimental and literature data for three other heavy oils were correlated with the solubility parameter theory (SPT) and equation of state (EOS) models. Project Leader: Amr Henni (U of R)

Solubility and Diffusion Coefficients of Gases in SARA Fractions and Heavy Oils

The solubilities and diffusion coefficients of CO_2, ethane and propane were measured in several western Canadian heavy oils and their SARA fractions. A gravimetric microbalance was used for pressures up to 2 MPa. An EOS model and an SPT model were used to correlate/predict the solubility data. This methodology may be used to measure gas adsorption in reservoirs. Project Leader: Amr Henni (U of R)

Other Projects

Intelligent Motor Drive

Development of an innovative permanent magnet wellhead motor went forward, with design of the controller and brake. The primary control of the motor was at first thought to be complete, but many issues in this area were found to need work. While it was initially assumed that the control of the motor would be from a Hall effect sensor to give an accurate position of the armature, the project found that the position of the motor can be determined with a new technique called Field Oriented Control (FOC). It is hoped the project can progress in 2009-10 towards the manufacture of these units in Saskatchewan. Project Leader: Ron Palmer (U of R)

Low-Cost Instruments for Heavy Oil Fields (Year 1)

In 2008-09, the project made significant progress in construction of devices to install in the field, but was unable to proceed to field tests owing to changes in market conditions for the client. Some additional laboratory tests were conducted, and some field tests were instigated by adapting the system to grain-bin moisture monitoring. The project is currently seeking a new industrial partner who is interested in field testing. Project Leader: Ken Runtz (U of R)

Petroleum Technology Research Centre Inc.

Auditors' Report

To the members of Petroleum Technology Research Centre Inc.

We have audited the statement of financial position of Petroleum Technology Research Centre Inc. as at March 31, 2009 and the statements of operations and unrestricted net assets and cash flows for the year then ended. These financial statements are the responsibility of the Centre's management. Our responsibility is to express an opinion on these financial statements based on our audit.

We conducted our audit in accordance with Canadian generally accepted auditing standards. Those standards require that we plan and perform an audit to obtain reasonable assurance whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation.

In our opinion, these financial statements present fairly, in all material respects, the financial position of the Centre as at March 31, 2009 and the results of its operations and cash flows for the year then ended in accordance with Canadian generally accepted accounting principles.

REGINA, Saskatchewan
May 7, 2009

Virtus Group LLP
Chartered Accountants

Petroleum Technology Research Centre Inc.

Statement of Financial Position

as at March 31, 2009

Statement A

	Petroleum Research Fund	JIVE Fund	Weyburn-Midale Fund	2009 Total	2008 Total
ASSETS					
CURRENT ASSETS					
Cash	$ 4,703,703	$ -	$ 2,647,082	$ 7,350,785	$ 4,326,226
Accounts receivable	6,542,457	223,111	2,154,560	8,920,128	3,479,160
Prepaid expenses	33,629	-	361,702	395,331	30,318
	11,279,789	223,111	5,163,344	16,666,244	7,835,704
PROPERTY, PLANT & EQUIPMENT - Note 3	240,789	-	-	240,789	303,859
	$ 11,520,578	$ 223,111	$ 5,163,344	$ 16,907,033	$ 8,139,563
LIABILITIES AND NET ASSETS					
CURRENT LIABILITIES					
Accounts payable and accrued liabilities	$ 1,138,192	$ 9,800	$ 720,999	$ 1,868,991	$ 2,174,587
DUE TO (FROM) OTHER FUNDS - Note 8	2,323,922	(2,317,118)	(6,804)	-	-
DEFERRED REVENUE - Note 4	7,728,498	2,530,429	4,230,980	14,489,907	5,835,819
	11,190,612	223,111	4,945,175	16,358,898	8,010,406
NET ASSETS					
Unrestricted - Statement B	329,966	-	218,169	548,135	129,157
	$ 11,520,578	$ 223,111	$ 5,163,344	$ 16,907,033	$ 8,139,563

Approved by the Board

Director

Director

See accompanying notes

Petroleum Technology Research Centre Inc.

Statement of Operations and Unrestricted Net Assets

For the year ended March 31, 2009

Statement B

	Petroleum Research Fund	JIVE Fund	Weyburn-Midale Fund	2009 Total	2008 Total
REVENUE					
Annual Funding					
- Saskatchewan Energy & Resources	$ 465,831	$ -	$ -	$ 465,831	$ 1,306,000
- Natural Resources Canada	142,500	-	-	142,500	911,000
Project Funding					
- Saskatchewan Energy & Resources	339,169		-	339,169	1,160,288
- Enterprise Saskatchewan		302,658		302,658	
- Western Economic Diversification Canada	100,000	-	-	100,000	63,021
- Natural Resources Canada	1,027,500	-	2,650,000	3,677,500	1,308,395
- Natural Resources Canada and US Department of Energy	-	-	-	-	400,000
- Industry, other leveraged sources	1,140,804	778,259	-	1,919,063	2,164,895
Other - Note 9	244,529	-	371,574	616,103	143,434
	3,460,333	1,080,917	3,021,574	7,562,824	7,457,033
OPERATING EXPENSES					
Amortization	23,068	-	-	23,068	27,988
Consulting	64,358	-	-	64,358	80,997
Financial systems support	46,029	-	37,125	83,154	123,185
Legal, audit and insurance	60,816	-	23,711	84,527	52,332
Publications and promotion	33,864	-	-	33,864	63,903
Rent, office and administration	136,360	-	72,970	209,330	153,556
Salaries and benefits	170,482	-	34,583	205,065	123,361
Travel and conferences	73,354	44	277	73,675	125,495
	608,331	44	168,666	774,041	750,817
PROJECT EXPENSES - Notes 3, 5	2,651,193	1,080,873	2,634,739	6,366,804	6,705,902
EXCESS OF REVENUE	200,809	-	218,169	418,979	314
UNRESTRICTED NET ASSETS (DEFICIT) - beginning of year	129,157	-	-	129,157	128,843
UNRESTRICTED NET ASSETS - end of year					
- Statement A	$ 329,966	$ -	$ 218,169	$ 548,136	$ 129,157

See accompanying notes

Petroleum Technology Research Centre Inc.

Statement of Cash Flows

For the year ended March 31, 2009

Statement C

	2009	2008
OPERATING ACTIVITIES		
Excess of revenue	$ 418,979	$ 314
Item that does not affect cash:		
- amortization - Notes 3, 5	101,277	139,715
	520,256	140,029
Net change in current assets	(5,805,981)	(1,461,466)
Net change in current liabilities	(305,596)	1,514,331
Net change in deferred revenue	8,654,088	1,942,383
Net cash from operating activities	3,062,767	2,135,277
INVESTING ACTIVITIES		
Purchase of property, plant and equipment	(38,208)	(32,088)
Net cash (used by) investing activities	(38,208)	(32,088)
INCREASE IN CASH RESOURCES	3,024,559	2,103,189
CASH - beginning of year	4,326,226	2,223,037
CASH - end of year	$ 7,350,785	$ 4,326,226

See accompanying notes

Petroleum Technology Research Centre Inc.

Notes to the Financial Statements

March 31, 2009

1. NATURE OF ORGANIZATION

The Centre is an internationally recognized innovative leader in the petroleum research and development area that delivers world-class basic and applied research for the benefit of the people of Saskatchewan, Canada and their customers around the globe. The Centre is incorporated under the *Canada Business Corporations Act* as a non-profit corporation and is exempt from income taxes on its income.

2. SIGNIFICANT ACCOUNTING POLICIES

These financial statements are prepared in accordance with Canadian generally accepted accounting principles and the significant policies are as follows:

Fund Accounting

The accounts of the Centre are maintained in accordance with the principles of fund accounting. For financial reporting purposes, accounts with similar characteristics have been combined into the following major funding groups:

i) **Petroleum Research Fund**

The Petroleum Research Fund reflects the primary operations of the Centre including revenues received from Saskatchewan Energy & Resources (SER), Natural Resources Canada (NRCan), Western Economic Diversification Canada (WD) and industry to fund its petroleum research operations. In 2008-09 initial work with a project focused on capture, transport, injection and storage of CO_2 from the CCRL refinery in Regina into a deep saline formation (Aquistore) has also been included but will be reported separately in 2009-10 when the project is established.

ii) **JIVE Fund**

The JIVE Fund reflects the operations for the collaborative project entitled Joint Implementation of Vapour Extraction. This multi-year project is funded by a consortium that includes Saskatchewan Energy & Resources (SER), Sustainable Development Technology Canada (SDTC) and three industry participants: Nexen Inc., Canadian Natural Resources Limited and Husky Oil Operations Ltd.

iii) **Weyburn-Midale Fund**

The Weyburn-Midale Fund reflects the operations for the multi-year collaborative project entitled Final Phase of the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project.

Revenue Recognition

The Centre follows the deferral method of accounting for contributions. Restricted contributions related to general operations are recognized as revenue of the Petroleum Research Fund in the year in which the related expenses are incurred. All other restricted contributions are recognized as revenue of the appropriate restricted fund in the year that related expenditures are incurred. Unrestricted contributions are recognized as revenue of the Petroleum Research Fund in the year they are received or receivable if the amount to be received can be reasonably estimated and collection is reasonably assured.

2. SIGNIFICANT ACCOUNTING POLICIES - continued

Property, Plant and Equipment

Assets of the Centre are stated at cost and are amortized over the estimated useful life of the assets, applying the following annual rates:

Computers	30% Declining balance method
Furniture and other equipment	20% Declining balance method
Research assets	30% Declining balance method
Leasehold improvements	Straight line method (3 years)

Foreign currency

Monetary items denominated in foreign currency are translated to Canadian dollars at exchange rates in effect at the statement of financial position date and non-monetary items are translated at rates of exchange in effect when the assets were acquired or obligations incurred. Revenues and expenses are translated at rates in effect at the time of the transactions. Foreign exchange gains and losses are included in other revenue.

Use of Estimates

The preparation of financial statements in accordance with Canadian generally accepted accounting principles requires management to make estimates and assumptions that affect the reported amount of assets and liabilities and disclosure of contingent assets and liabilities at the date of the financial statements and the reported amount of revenues and expenses during the reported period. Since actual results may differ from the estimates, these estimates are reviewed periodically, and, as adjustments become necessary, they are reported in earnings in the period in which they become known.

Financial Instruments – Recognition and Measurement

Financial assets and liabilities are initially recognized at fair value and their subsequent measurement is dependent on their classification. Their classification depends on the purpose for which the financial instruments were acquired or issued, their characteristics and the Centre's designation of such instruments. The standards require that all financial instruments, including all derivatives, be measured at fair value with the exception of loans and receivables, debt securities classified as Hold to Maturity (HTM), and Available for Sale (AFS) financial assets that do not have quoted market prices in an active market.

Financial assets are classified as held-for-trade or loans and receivables. Cash is designated as held-for-trade and is carried at fair value. All receivables are designated as loans and receivables and are accounted for at amortized cost.

Financial liabilities are classified as other liabilities and are accounted for at amortized cost, with gains and losses reported in excess of revenue in the period that the liability is derecognized.

Financial Instruments – Disclosure and Presentation

The Centre has elected to continue to apply Section 3861, Financial Instruments – Disclosure and Presentation.

3. PROPERTY, PLANT AND EQUIPMENT

	2009			2008
	Cost	Accumulated Amortization	Net Book Value	Net Book Value
Computers	$ 41,698	$ 15,746	$ 25,952	$ 30,714
Office furniture	43,839	21,353	22,486	12,448
Subtotal	85,537	37,099	48,438	43,162
Leasehold improvements	14,794	4,931	9,863	-
Research assets	532,034	349,546	182,488	260,697
Total	$ 632,365	$ 391,576	$ 240,789	$ 303,859

Research asset amortization of $78,209 (2008 - $111,727) is included in project expenses.

The Centre's net investment in property, plant and equipment represents $58,301 (2008 - $43,162) of net unrestricted assets, calculated as total net book value less deferred revenue related to research assets.

4. DEFERRED REVENUE

The Centre receives contributions from government and industry for specific projects or programs. These funds are restricted in use as directed by the external sponsors. The Centre recognizes revenue for these projects on the same basis as expenditures are incurred. Any excess revenue in the year is deferred and recognized in future years as expenditures are incurred. Funding for research assets and prepaid maintenance contracts are also recorded as deferred revenue until such time as the related assets are put in use and amortized.

As at March 31, 2009, deferred revenue of $7,728,498 (2008 - $1,095,146) was held in the Petroleum Research Fund to be matched with future project expenditures and asset amortization, including $2,625,000 applicable to the STEPS program and $3,006,818 applicable to the Aquistore project (both described in Note 6).

As at March 31, 2009, deferred revenue of $2,530,429 (2008 - $1,835,658) was held in the JIVE Fund to be matched with future project expenditures.

As at March 31, 2009, deferred revenue of $4,230,980 (2008 - $2,905,015) was held in the Weyburn-Midale Fund to be matched with future project expenditures.

Notes to the Financial Statements

5. PROJECT EXPENSES

During the year, the Petroleum Research Fund incurred project expenses of $2,651,193 (2008 - $3,391,079).

	2009	2008
EOR Research Program	$ 2,330,678	$ 1,949,318
Other Research	294,033	1,257,149
Other Business	26,482	184,612
	$ 2,651,193	$ 3,391,079

The annual EOR Research Program is a collaborative petroleum research program designed to develop innovative technologies for improved oil production. This program attracts both domestic and international industry funding. The Other Research category is comprised of smaller collaborative research projects, incubation projects and equipment projects. The Other Business category contains projects designed to enhance the Centre's research and engineering capacity.

Other Business project expense includes $78,209 (2008 - $111,727) for amortization of research assets.

Project expenditures for the JIVE Fund are reported in detail to the funding organizations.

Project expenditures for the Weyburn-Midale Fund are detailed in Schedule 1 of the financial statements.

6. SIGNIFICANT AGREEMENTS

The Centre has funding agreements in place at March 31, 2009 to support the Joint Implementation of Vapour Extraction project ($1,290,000 remaining to be invoiced before October 5, 2010) and the Final Phase of the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project ($4,800,000 remaining to be invoiced before March 31, 2011). Both projects were granted extensions in 2008-09 and the previous end dates were June 30, 2009 (JIVE) and March 31, 2010 (Weyburn-Midale).

Within the Petroleum Research Fund, the EOR program is being expanded into a new Business-Led Network of Centres of Excellence being managed by PTRC from 2009-2013 called "STEPS". An agreement was signed with the Natural Sciences and Engineering Research Council ("NSERC") and the Social Sciences and Humanities Research Council ("SSHRC") representing a total award of $10,500,000 to be paid through 2012. Agreements were also signed for the Aquistore project with Sustainable Technology Development Canada (SDTC) for $5,000,000 over the period 2009-2013 and the Saskatchewan Ministry of Environment for $5,000,000 for the same period. The Aquistore project will conduct research on the capture, transport, injection and storage of CO_2 from the CCRL refinery in Regina into a deep saline formation and will be reported in a separate fund in 2009-10.

Notes to the Financial Statements

7. ECONOMIC DEPENDENCE

Funding commitments were executed in 2008-09 with Natural Resources Canada and Saskatchewan Energy & Resources for research projects and operations through March 31, 2011. A funding agreement with Western Economic Diversification for $1,000,000 over a three-year period ending March 31, 2011 was executed on April 1, 2008.

The Centre seeks additional funding for its research projects from other federal sources and from the petroleum industry. In 2008-09 a multi-year funding agreement for the EOR Research Program was executed with 9 industry funders.

8. DUE TO (FROM) OTHER FUNDS

The Petroleum Research Fund holds the cash and makes all payments on behalf of the JIVE Fund. As of March 31, 2009, the Petroleum Research Fund owed the JIVE Fund $2,317,118 (2008 - $1,670,749).

The cash of the Weyburn-Midale Fund is segregated from the Petroleum Research Fund; payments are, however, made from one fund on behalf of the other occasionally. As of March 31, 2009, the Petroleum Research Fund owed $6,804 (2008 – ($420,934)) to the Weyburn-Midale Fund.

9. UNREALIZED GAIN (LOSS)

In the Weyburn-Midale Fund the unrealized gain of $261,404 (2008 - ($26,320)) has been reclassified as other income. Due to the appreciation in the Canadian dollar, this amount is significant.

10. FINANCIAL INSTRUMENTS

Fair Value of Financial Instruments

The carrying amount of cash, accounts receivable and accounts payable approximates their fair market value because of the short-term nature of these items.

Credit Risk

The Centre does not believe it is subject to any significant concentration of credit risk on any of its customers.

11. COMPARATIVE FIGURES

Certain of the 2008 financial statement balances have been reclassified to conform to the current year's presentation.

Petroleum Technology Research Centre Inc.

Schedule of Revenue and Expenditure Weyburn-Midale Fund

as at March 31, 2009

Schedule 1

	2009 Cumulative Project-to-Date	2009 Annual Activity	2008 Annual Activity
REVENUE			
Government Funding			
Natural Resources Canada	$ 4,230,000	$ 2,650,000	$ 380,000
Natural Resources Canada and US Department of Energy	1,249,318	-	400,000
Enterprise Saskatchewan			
(formerly Saskatchewan Industry & Resources)	1,200,000	400,000	400,000
Alberta Innovation and Science	300,000	-	-
	6,979,318	3,050,000	1,180,000
Industry Funding			
Aramco Services	595,264	117,285	72,547
Chevron Energy Technology Company	324,932	106,722	99,290
Dakota Gasification	135,000	135,000	-
Nexen Inc.	224,283	126,285	97,998
OMV Austria	530,911	106,722	424,189
Research Institute of Innovative Technology for the Earth	409,484	100,619	92,602
SaskPower	434,999	107,326	105,200
Shell Exploration and Production Company	630,743	126,006	504,737
	3,285,616	925,965	1,396,563
Other Revenue	445,894	371,574	70,632
Revenue Deferred for Future Use	(4,230,980)	(1,325,965)	(1,577,860)
Total Revenue	$ 6,479,848	$ 3,021,574	$ 1,069,335
EXPENSES			
Technical Program			
Theme 1 - Site Characterization	$ 488,846	$ 293,630	$ 17,953
Theme 2 - Wellbore Integrity	585,653	223,820	73,104
Theme 3 - Distribution & Fate of CO_2	1,384,702	719,810	141,236
Theme 4 - Performance Assessment	415,350	251,714	154,251
Theme 5 - Shared Data Environment	351,474	115,997	82,465
Information Integration	1,054,500	575,852	176,423
Project Control	1,146,109	351,308	237,849
Sponsorship Campaign	23,904	247	1,144
Promotional Travel	34,119	4,917	14,195
Non-Technical Program			
Policy & Regulation	145,124	97,444	16,447
Subtotal Project Expenses	5,629,781	2,634,739	915,067
Administrative and Overhead	631,898	168,666	154,268
Total Expenses	$ 6,261,679	$ 2,803,405	$ 1,069,335
EXCESS OF REVENUE	$ 218,169	$ 218,169	$ -

This schedule shows the cumulative revenue, deferred revenue and expenses for the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project since its planning activities began in January, 2004 as well as the annual activity for the years ended March 31, 2009 and March 31, 2008. In-kind services provided by industry partners are not reflected in this schedule.

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Petroleum Technology Research Centre

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