Alberta Energy
Oil Sands Development

Alberta Energy
Research Institute

Oil Sands Research Inventory

March 2004

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NOTE: Further updates to this inventory may be periodically undertaken by the Government of Alberta.

Abbreviations

AACI	AERI-ARC Core Industry program
ACR	Alberta Chamber of Resources
ADOE	Alberta Department of Energy
AERI	Alberta Energy Research Institute
ARC	Alberta Research Council
ASRIP	Alberta Science and Research Investment Program
CANMET	Canada Centre for Mineral and Energy Technology
CETC	CANMET Energy Technology Centre
CFI	Canada Foundation for Innovation
COURSE	Core University Research in Sustainable Energy
CRC	Canada Research Chairs
CSS	Cyclic Steam Stimulation
EUB	Energy and Utilities Board
IRAP	Industrial Research Assistance Program
NCUT	National Centre for Upgrading Technology
NRC	National Research Council
NRCan	Natural Resources Canada
NSERC	National Science and Engineering Research Council
OSTRM	Oil Sands Technology Road Map
PTAC	Petroleum Technology Alliance of Canada
PTRC	Petroleum Technology Research Centre
SAGD	Steam Assisted Gravity Drainage
SRC	Saskatchewan Research Council
TPC	Technology Partnerships Canada
VAPEX	Vapour Recovery Extraction
URSI	University Research and Strategic Investments

Executive Summary

Total funding for bitumen and heavy oil R&D was approximately $117 million in the five years from fiscal 1998-99 to fiscal 2002-03. The funding organizations that provided the most funds were by a wide margin Natural Resources Canada (NRCan) ($46.7 million) and the Alberta Energy Research Institute (AERI) ($30.6 million). NRCan funding was almost exclusively directed to the operations of the laboratories and pilot plants located in Devon Alberta. AERI, by contrast funded a broad mix of targeted projects from fundamental research to commercialization performed by several facilities and sites.

Funding to universities was mostly through programs such as the Canada Foundation for Innovation, Canada Research Chairs, NSERC and programs administered by Alberta University Research and Strategic Investments. In aggregate, these funding agencies provided approximately $23 million over 5 years, primarily to universities. These funding programs support the infrastructure needs of universities as well as research chairs. These types of projects are often of a very broad scope and are useful to more than one industry.

Public funds provided for oil sands research were utilized by research organizations to conduct projects. The largest recipient ($38.9 million) was the National Center for Upgrading Technology (NCUT) in Devon, Alberta which is a federal-provincial partnership and received funds from NRCan, AERI, ARC, as well as other government sources. This facility is dedicated to research into the upgrading of bitumen and heavy oil into synthetic crude oil and transportation fuels such as gasoline, diesel and jet fuel. The second largest investment was for the associated federal CANMET facility in Devon ($18.7 million). This facility is funded by NRCan and industry. It conducts research into advanced separation technologies related to petroleum. The University of Alberta, the Alberta Research Council and the University of Calgary each received approximately $12 million over five years for bitumen and heavy oil research.

The largest amount of funding was directed at applied research and reflects the substantial amount of work conducted by NCUT and ARC. The next largest category is fundamental research which is conducted mostly by universities. Demonstration trials attracted a relatively small level of funding. For fundamental and applied research to be commercialized and produce an economic impact, it is necessary to demonstrate it at a pre-commercial scale. This study appears to indicate that a large amount of technology developed in the laboratory will not be commercialized because of insufficient investment in demonstration trials. However, anecdotal information indicates that some demonstration trials are proceeding in Alberta and Saskatchewan without support from public funds. In order to draw conclusions and policy recommendations it would therefore be important to conduct a survey of privately funded research and demonstration trials in order to construct the complete picture on oil sands R&D.

Projects concerned with bitumen and heavy oil initial recovery attracted the most funding. A relatively small amount was spent on recovery techniques to follow-up on

initial recovery and to improve overall recovery. This relationship is reasonable given the fact that oil sands developments are at an early stage. Upgrading commanded the second most important level of funding. This is due in a large part to the research conducted at the National Center for Upgrading Technology. It is important to underscore that the lowest level of funding was directed at research conducted into environmental issues. The aggregate amount of funds spent on environmental research was slightly more than 10% of the total amount spent on oil sands research. This percentage is small considering the importance of cradle to grave management of natural resources, particularly when exploitation has the potential to result in significant environmental impact. In particular, it is worth pointing out that the smallest amount spent on environmental issues was related to remediation and reclamation. It should be clear that more needs to be done in this area because of the requirement for remediation and reclamation of land once oil sands have been exploited.

A small fraction of oil sands reserves is suitable for existing in-situ technologies such as Steam Assisted Gravity Drainage (SAGD) and Cyclic Steam Stimulation (CSS). The other types of in situ deposits can not be economically developed unless new technology is made available. Examples of undeveloped reservoir types are low-pressure reservoirs, shallow reservoirs and thin reservoirs. In addition, over 1,200 billion barrels of in situ deposits are found in unclassified reservoirs. There are also significant reserves in carbonate reservoirs located nearby the oil sands. Therefore there is an enormous economic prize for the development of new technologies that would permit the commercial exploitation of new types of reservoirs.

Most of the research appears to have been directed at improving the efficiency of existing or near commercial technologies designed for reservoir types that are presently the object of active development. A much lower level of funding was targeted at marginal reservoirs that would need to be developed in the future in order to maintain the economic contribution that oil sands are making to the Alberta economy. The reservoir type that attracted the most funding was “Current SAGD and CSS”. This is not surprising given the large size of this reservoir type. The fact that a significant amount of research was conducted on vapour recovery technologies resulted in important amounts of funding being assigned to shallow and primary production reservoir types. Very little work appears to have been directed at thin reservoirs. No projects could be identified that targeted bitumen in carbonate reservoirs.

The continued exploitation of oil sands reservoirs under active development with existing technologies is also faced with significant challenges. Natural gas consumption and energy costs are rising. Water and diluent consumption are increasing while availability is limited. These industry challenges represent opportunities for the development of new technologies.

The improvement opportunity that attracted the most research funding was “Reduced Energy Intensity”. This is not surprising given the importance of energy costs, particularly natural gas usage, in the development of oil sands.

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Purpose

Alberta oil sands contain the world largest reserves of bitumen, with a magnitude comparable to the reserves of conventional crude oil of Saudi Arabia. The development of this abundant resource using technologies that are both economic and respectful of the environment is a significant component of present and future energy supply to Alberta and North America.

The following is a vision for oil sands prepared by the Oil Sands Development Business Unit of the Alberta Department of Energy to assist with planning and for strategic assessment purposes:

> *"To pave the way for Alberta's bitumen production to reach 3 million barrels per day by 2020 while minimizing overall costs and the environmental footprint. A significant portion of this production will involve value-added processing within Alberta."*

Historically, research and development has played a critical role in the successful development of the oil sands sector by making available critical technologies such as Steam Assisted Gravity Drainage (SAGD). Today, several research organizations are focused on developing the next generation of oil sands technology. In order to develop appropriate policies, it is imperative that the Department of Energy, Oil Sands Development Business Unit have a solid understanding of new technologies being developed and where the efforts are focused from exploration, production, upgrading through to lease closure and reclamation.

Sponsored by the Alberta Department of Energy (ADOE) and by the Alberta Energy Research Institute (AERI), the purpose of this study is to document the intent and the level of effort for publicly funded oil sands and heavy oil research. Establishing an inventory of oil sands research projects is supportive of the following objective that reflects the strategic direction being explored by the Oil Sands Development Business Unit:

"To successfully develop the next stage of the oil sands resource by identifying what research is taking place today, comparing that with reserve characteristics, and then facilitating technology development accordingly."

Scope

The first task of this study was to develop background information about publicly funded oil sands R&D in Alberta and Canada, whether it is conducted by government or academic institutions. The information acquired, analyzed and summarized by this review will support current activities at ADOE. It will constitute an information resource that will be used to answer key questions about oil sands R&D: (e.g. how much is being spent on oil sands R&D? Who is funding R&D? Which institutions perform R&D?)

The second task was to match R&D projects with the overall needs and challenges of the industry and to map them to major reservoir types. This will serve to improve understanding of the alignment between technology development and long term oil sands opportunities. The R&D inventory will assist in matching technology with reserve characteristics and of identifying suitable areas for R&D policy initiatives. This work will form the foundation for a subsequent study which will compare R&D programs and successes to the needs of specific oil sands deposits in order to determine where:

- Processes are in place for all elements from exploration to lease closure
- Processes are being developed and their stage of development
- Specific gaps exist in development efforts.

The scope includes bitumen and heavy oil research and development projects conducted in Canada during the last five years, from fiscal 1998-1999 to fiscal 2002-2003.

Methodology

The study was conducted in January to March 2004 by Dr. Ted Heidrick and Victor Bilodeau of the University of Alberta and by Marc Godin of Portfire Associates.

The process involved collaborative work with ADOE and the Alberta Energy and Utilities Board (EUB). The study built on existing databases within ADOE and AERI, on recently completed and ongoing AERI evaluation reports and on a review of the public literature. In particular, the comprehensive Oil Sands Technology Road Map (OSTRM) recently completed by the Alberta Chamber of Resources (ACR) was an important foundation.

The tasks performed involved the acquisition of information about publicly funded R&D from funding agencies and research providers. Funding agencies consulted appear on Table 1 while research providers are shown on Table 2. R&D efforts were categorized in terms of reservoir type, life cycle focus of the effort (exploration, production, upgrading, refining, environmental, sustainability, lease closure, etc.), technology focus (e.g.: a specific recovery technology), stage of development (basic, applied, demonstration, commercialization.) and level of effort (dollars).

Reservoir Prototypes Workshop

The first step was to identify overall reservoir types as well as current and future industry challenges. Alberta oil sands are not a uniform resource. There are different types of reservoirs for which different technologies are applicable. For example, conventional SAGD would not be applied to shallow or thin deposits. One of the first steps in this study was therefore be to list and define the reservoir prototypes that are likely to constitute the next wave of oil sands development over the next 20 years. A workshop was conducted with EUB and ADOE experts to achieve this purpose.

Review of AERI and Industry Sponsored R&D

AERI has recently completed evaluations of its upgrading program, of its recovery oriented joint program with industry, and of its University/Industry program. During the course of these studies interviews were done with most companies doing oil sands related research work in the province. The reports from these reviews were used to compile a baseline of information about oil sands R&D.

Table 1 – Funding Agencies

- Alberta Energy Research Institute (AERI)
    - Core University Research in Sustainable Energy (COURSE)
    - Industry Research Program
    - Core funding to AERI-ARC Core Industry program (AACI)
    - Core funding to the National Centre for Upgrading Technology (NCUT)
- Natural Resources Canada (NRCan):
    - Canada Centre for Mineral and Energy Technology (CANMET)
    - National Centre for Upgrading Technology (NCUT)
- Canada Foundation for Innovation (CFI)
- Canada Research Chairs (CRC)
- Alberta University Research and Strategic Investments (URSI)
- National Science and Engineering Research Council (NSERC)
- Alberta Research Council (ARC)
- Technology Partnerships Canada (TPC)
- Saskatchewan Research Council (SRC) and Petroleum Technology Research Centre (PTRC)

Review of Federal Government Programs

Federal government agencies also operate R&D laboratories related to oil sands. In collaboration with the Alberta Chamber of Resources, NRCan (CANMET and NCUT) recently published the oil sands technology roadmap. The National Research Council (NRC), the Industrial Research Assistance Program (IRAP), and Technology Partnerships Canada (TPC) are also actively involved with Alberta energy companies.

Review of Programs at Provincial Research Centres

The Alberta Research Council (ARC) and the Saskatchewan Research Council (SRC) conduct R&D in partnership with industry in the areas of oil sands and heavy oil. Their programs were summarized by reviewing public information provided by these institutions and by direct consultations.

Canadian University Research

Several Canadian universities have active research programs in areas that are relevant to oil sands exploitation. Some of this research is funded by NSERC and other related agencies that fund innovation in Canada. A review of public information available from Canadian universities was used to prepare a summary of oil sands related R&D at Canadian universities.

Table 2 – Research Providers
❑ University of Alberta ❑ University of Calgary ❑ AERI-ARC Core Industry (AACI) ❑ National Centre for Upgrading Technology (NCUT) ❑ Canada Centre for Mineral and Energy Technology (CANMET) ❑ Saskatchewan Research Council (SRC) and Petroleum Technology Research Centre (PTRC) ❑ Other Canadian universities

Alberta Oil Sands

Alberta oil sands are the world's largest reserves of bitumen. Their magnitude is comparable to the reserves of conventional crude oil of Saudi Arabia. Oil sands are found in three places in Alberta – the Athabasca, Peace River and Cold Lake regions – and cover a total of nearly 141,000 square kilometres.

Supply and Demand

Recovery of this vast resource is becoming an increasingly important strategic area of economic activity in the province. Existing mining operations are being expanded, and new mining and in-situ recovery projects are being developed. According to Alberta Economic Development (October 2003), total oil sands industry investment in new and sustaining capital may reach $93.5 billion in the 1996 to 2012 period. Spending on new and sustaining capital in the 1996-2002 period amounted to $22.5 billion.

While conventional crude oil flows naturally or is pumped from the ground, oil sands recovery presents significant technical challenges. Deposits must be mined or recovered using in situ methods.

Mineable bitumen deposits are located near the surface and can be recovered by open-pit mining techniques. About two tonnes of oil sands must be dug up, moved and processed to produce one barrel of oil. Roughly 75 % of the bitumen can be recovered from this sand. Processed sand has to be returned to the pit and the site reclaimed. Technology developments over the past decades have been critical in making oil sands recovery economic and enabling the current scale of commercial development. For example, the Syncrude and Suncor oil sands operations near Fort McMurray, Alberta, use the world's largest trucks and shovels to economically recover bitumen.

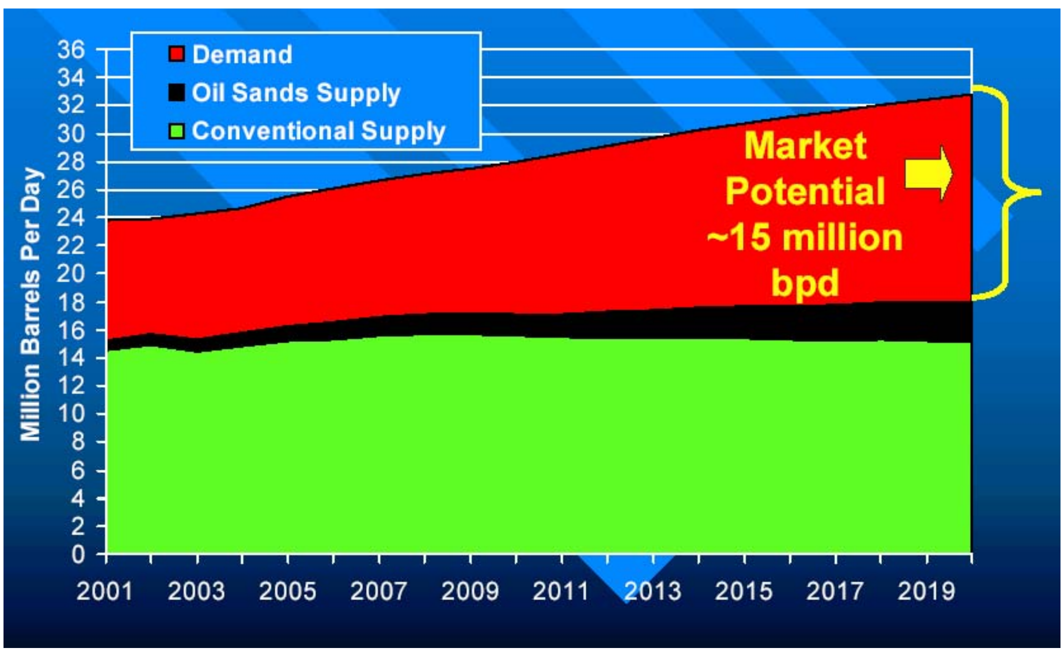
In situ recovery is used for bitumen deposits buried too deeply – more than 75 meters – for mining to be practical. Most in situ bitumen and heavy oil production comes from deposits buried more than 400 meters below the surface. Innovative technologies such as Cyclic Steam Stimulation (CSS) and Steam-Assisted Gravity Drainage (SAGD) have been developed to allow commercial exploitation of buried deposits. Novel technologies are emerging such as pulse technology and Vapour Recovery Extraction (VAPEX).

New technologies will be required to improve production of bitumen and heavy oil, whether it is to increase the extent of recovery, to increase the rate of recovery, to lower costs or to minimize environmental footprint. The future of oil production in Alberta lies with improved bitumen recovery. This can be accomplished by incremental improvements to existing methods, or, developing new and novel ones. Oil sands research and development is an important vehicle for the emergence of the innovative technologies that will be necessary to economically recover Alberta's vast remaining bitumen resource.

Over the past ten years, global demand for crude oil has increased by an average of 1.4 % per year. In the last 3 years, there has been virtually no growth in global crude oil demand. High crude oil prices and the sluggish economic recovery in both the U.S. and global markets resulted in weak demand for crude oil and products. However, as the global economy continues to improve, the global demand for oil is expected to increase by between 1.0 and 1.5 per cent in 2004. If a 1.0 to 1.5 % growth rate in global demand is realized over the next few years, global crude oil production will increase by 8 million to 12 million barrels per day by 2012 to meet demand.

As shown on Figure 1, a similar demand scenario is expected to unfold in North America. Demand is forecasted to increase from 24 million barrels per day to approximately 33 million barrels per day in 2020. On the other hand, North American supply from conventional sources is expected to slowly decline over the same period.

Figure 1 - North American Petroleum Supply and Demand



Source: ADOE 2004

Oil sands production is shown to increase from approximately 1 million barrels per day at the present time to 3 million barrels in 2020. However, this threefold increase, while impressive, is not sufficient to offset the combined effect of declining conventional production and demand expansion. The market opportunity for increased oil sands production therefore nearly doubles from 8 million barrels per day today to 15 million barrels be day in 2020. This market opportunity is currently filled by oil imports from other regions such as Mexico, Venezuela and the Middle East.

However, because of inherent deficiencies, crude bitumen may not be used in large quantities by North American refineries. The first step in adding value is transforming bitumen into a product equivalent to crude oil. Upgrading the bitumen to synthetic crude oil (SCO) is required. Advanced process and catalyst technologies are required for upgrading bitumen. There are currently three oil sands upgraders in Alberta converting crude bitumen into SCO for sale to Canadian and United States refineries. Upgraded Alberta bitumen can fulfill the immediate and future need of North American refiners for new, reliable, and large volume sources of high quality SCO.

However, SCO is no different than conventional crude oil in that it cannot be used directly as a transportation fuel. The second value added step involves the refining of oil into gasoline, diesel and jet fuel. Sophisticated separation and catalyzed processes are employed for delivering high performance fuels that meet tighter and tighter environmental and safety specifications. Research is also being conducted into technologies for upgrading bitumen directly to transportation fuels in integrated upgrader and refinery complexes. The presence of hundreds of years of oil reserves in the Alberta oil sands provides the opportunity for increasing the extent of value added refining in the province.

The third value added step is the production of petrochemicals directly or as a by-product of bitumen upgrading. Specialty and commodity petrochemicals can be produced in Alberta from energy feedstocks. Exports of crude oil may earn US$ 20-30 per barrel, but petrochemical products sell for over US$ 40 per barrel on world markets.

Adding value to oil sands by further upgrading and processing in Alberta benefits the province by creating new investment, new economic activity and employment. It also contributes to building the critical mass of knowledge and expertise in the province that is the source of further value adding innovations. These avenues are very attractive for Alberta because of their value-added nature, but they represent significant technical and economic challenges. Focused R&D will need to be undertaken to fully unlock the value-added potential of Alberta oil sands.

Major Reservoir Types

Reaching a target of 3 million barrels per day of bitumen and synthetic crude in 2020 is likely to have the following economic benefits for the province of Alberta:

- Over $80 billion invested between 2003 and 2020
- Over 10,000 new jobs created at oil sands plants
- Over 52% of Alberta's not renewable resource revenues to come from oil sands.

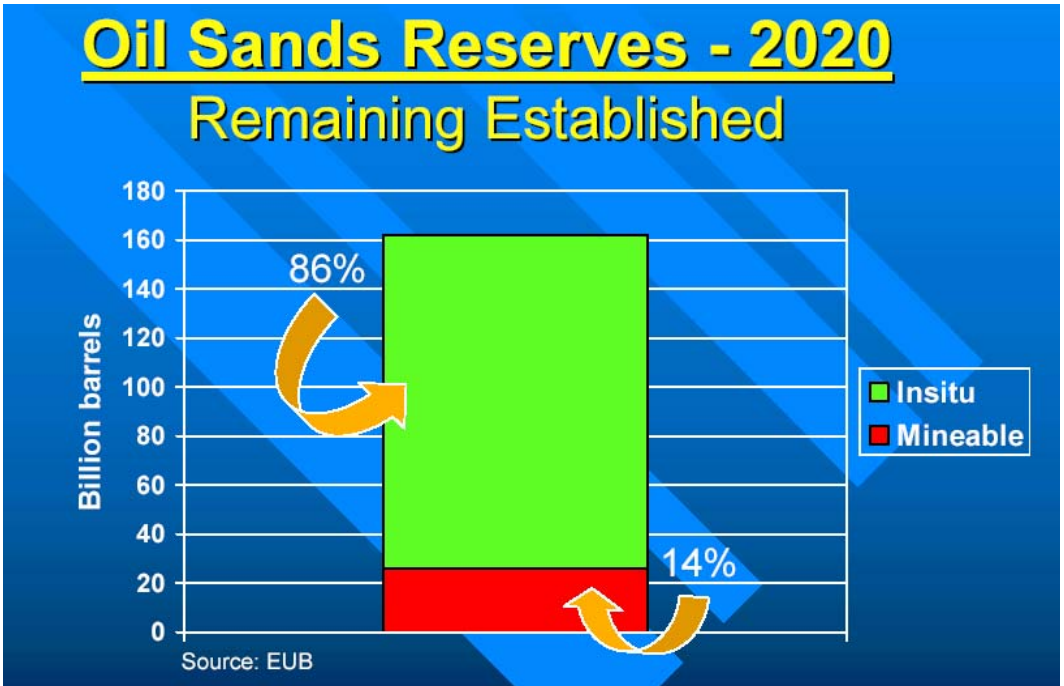
However, this path to growth is faced with several challenges and opportunities, many of which can be addressed through innovation and new technologies. Of particular importance is the fact that existing oil sand developments are occurring only on a small fraction of oil sands deposits. The reservoirs that are the most amenable to development utilizing current technologies are the first ones to be exploited. The fact that the oil sands resource is very heterogeneous means that the vast majority of oil sands reservoirs are not targets for present exploitation because of the absence of suitable technology.

In 2002, Alberta produced 193 million barrels from mineable reserves and 109 million barrels from in situ reserves. Total bitumen production, which exceeded total conventional crude oil production for the first time in 2001, will continue to grow and become a major source of export revenues.

Today, mineable reserves account for approximately 70% of oil sands reserves under active development, despite the fact that mineable reserves represent only about 19% of remaining established reserves. As illustrated on Figure 2, continued development of mineable reserves will decrease their proportion of total remaining established reserves to 14% in 2020. Given the forecasted production from oil sands mines in 2020, the reserve life index for mineable reservoirs in 2020 is expected to be another 25 years.

The balance of oil sands remaining established reserves, or 86%, will come from in situ deposits which are far more abundant and often more challenging to exploit than mineable reserves. The reserve life index in 2020 from in-situ reserves is forecasted to be an impressive 675 years.

Figure 2 - Oil Sands Reserves in 2020

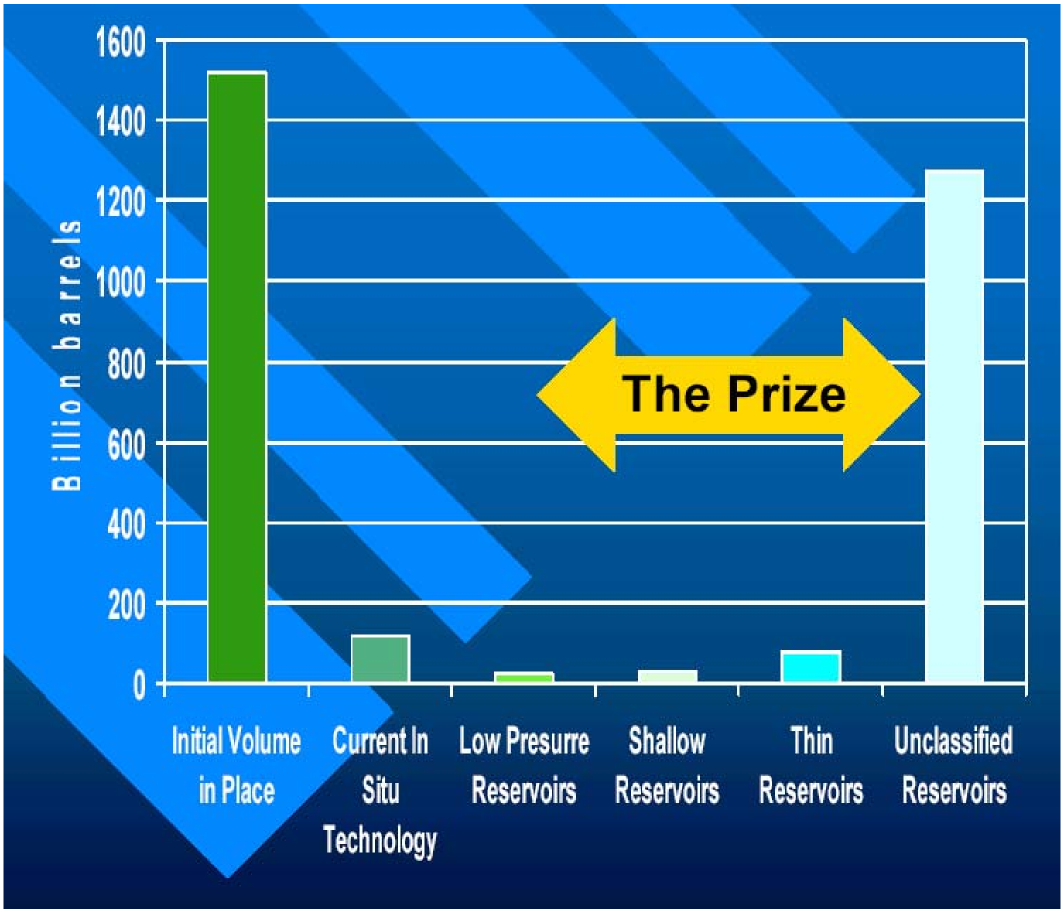


	Reserve Life Index - 2020
Mineable	25 years
In Situ	675 years

Source: ADOE 2004

As illustrated in Figure 3, the total in-place volume for in-situ deposits is estimated at 1,500 billion barrels. It is important to note that the scale on Figure 3 is one order of magnitude larger than the scale on Figure 2. This underscores the immensity of in place oil volume in oil sands deposits. Of this volume, a small fraction, approximately 140 billion barrels is suitable for existing in-situ technologies such as Steam Assisted Gravity Drainage (SAGD) and Cyclic Steam Stimulation (CSS). The other types of in situ deposits can not be economically developed unless new technology is made available. Examples of undeveloped reservoir types are low-pressure reservoirs, shallow reservoirs and thin reservoirs. In addition, over 1,200 billion barrels of in situ deposits are found in unclassified reservoirs. Therefore there is an enormous economic prize for the development of new technologies that would permit the commercial exploitation of new types of reservoirs.

Figure 3 - In-Situ Bitumen In-Place Volume



Source: ADOE 2004

In order to investigate, document, and quantify the opportunity presented by reservoir types for which new technology needs to be developed, a workshop was held with experts from the EUB and from ADOE. The output from the workshop is represented on Tables 3 and 4.

Mineable reservoirs are the resource which was exploited first and which represents approximately 70% of the oil sands reservoirs currently under active development.

All other reservoirs are buried, or in-situ, and the total in-place volume of in-situ deposits amounts to 241 billion m^3 (approx. 1,500 billion barrels). Of this massive resource, 69 billion m^3, or 29%, are deemed suitable for current SAGD and CSS technologies.

Reservoirs for which technology needs to be developed include:

- *Reservoirs Thinner than Current SAGD and CSS*: deposits too thin for conventional SAGD and CSS but exhibiting high quality saturation

- *Shallower Depth than Current SAGD and CSS*: deposits too shallow for conventional SAGD and too deep for surface mining, but exhibiting high quality saturation
- *Reservoirs in Communication with Gas Caps*
- *Bitumen in Carbonates*: bitumen and heavy oil deposits in carbonate formations

In-place volumes for thin, shallow and carbonates reservoirs were provided by the EUB. The in-place volume for reservoirs in communication with gas caps was provided by ADOE.

In addition to the exploitation of new bitumen reservoirs, innovative technologies are required to increase the total recovery achievable with existing technologies. In particular, reservoirs exploited with CSS realize a recovery rate of 25%, therefore leaving 75% on the oil in the ground. Bitumen reservoirs that are being developed using cold production (primary production) are similarly subject to relatively low rates of recovery ranging from 5% to 15%. New technologies with higher total recovery could replace existing methods or be applied as follow-up techniques after the potential for primary exploitation has been exhausted.

Opportunities are only briefly outlined in this report. A more detailed description of the challenges and opportunities is given in Appendix A which contains a very comprehensive description prepared by the Alberta Department of Energy.

Table 3 - Reservoir Types

	Mineable	**In-Situ**		
		SAGD and CSS	**Cold Lake (Primary bitumen production)**	**Athabasca and Peace River (Primary bitumen production)**
Depth	< 40-45 m	> 75-80 m	Bitumen in reservoirs capable of some primary production	
Thickness	> 3 m	> 10 m		
Saturation	> 7 % mass	> 6 % mass		
In Place Volume	9.4 billion m^3	~ 69 billion m^3	~ 22 billion m^3	~ 2 billion m^3
Current Recovery	82 % (mining and processing)	SAGD 50 % CSS 20 %	5 % (without water flood and horizontal well)	5-10 % (with water flood & horizontal well)
Opportunities	Improved upgrading	Follow-up, particularly for CSS	Follow-up and new methods	Follow-up and new methods

Sources: ADOE, EUB, 2004

Table 4 - Reservoir Types					
	In-Situ				**Others**
	Reservoirs in Communication with Gas Caps	**Thinner Than Current SAGD and CSS**	**Shallower Depth Than Current SAGD and CSS**	**Bitumen in Carbonates**	
Depth	> 75-80 m	> 75-80 m	40 m to 80 m	Bitumen in carbonate reservoirs	
Thickness	> 20 m	10 m to 1.5 m	> 10 m		
Saturation	> 6 % mass	> 8 – 10 % mass	> 6 % mass		
In Place Volume	~ 8 billion m^3	~ 12 billion m^3	~ 4.4 billion m^3	71.1 billion m^3	~ 61 billion m^3
Current Recovery	Uncertain	0 %	0 %	0 %	0 %
Opportunities	Low pressure SAGD Re-pressure reservoir	New exploitation methods	New exploitation methods	New exploitation methods	Long-term opportunities
Sources: ADOE, EUB, 2004					

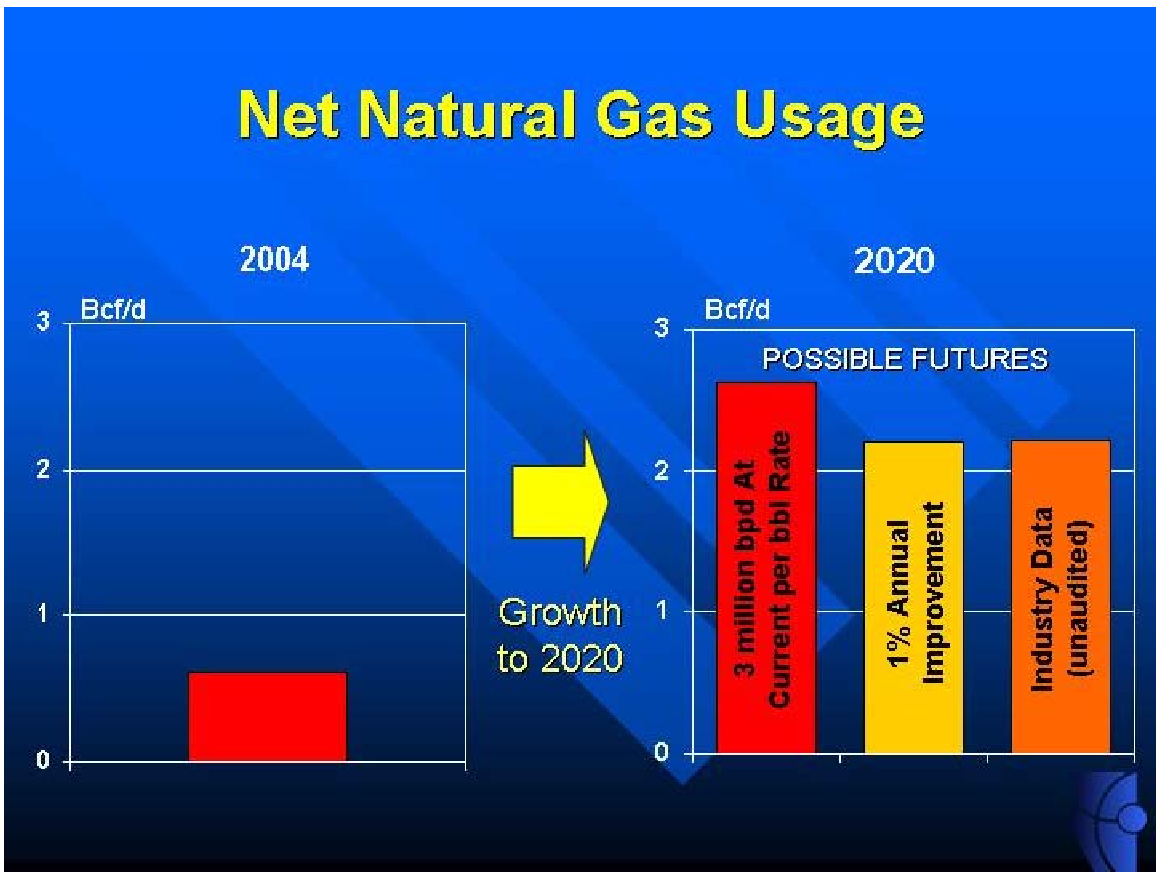
Industry Challenges

The continued exploitation of reservoirs under active development with existing technologies is also faced with significant challenges.

Natural Gas Usage

The development of oil sands is currently an energy intensive undertaking. As per Figure 4, in 2004 it is estimated that oil sand developments require approximately 0.7 bcf per day of natural gas. Forecasted industry growth to 3 million barrels per day of bitumen production would entail, using existing technology, a consumption of over 2.5 bcf per day of natural gas. Such high level of consumption is likely to impact the price of natural gas and the ability of maintaining natural gas exports.

Figure 4 - Net Natural Gas Usage in the Oil Sands Industry

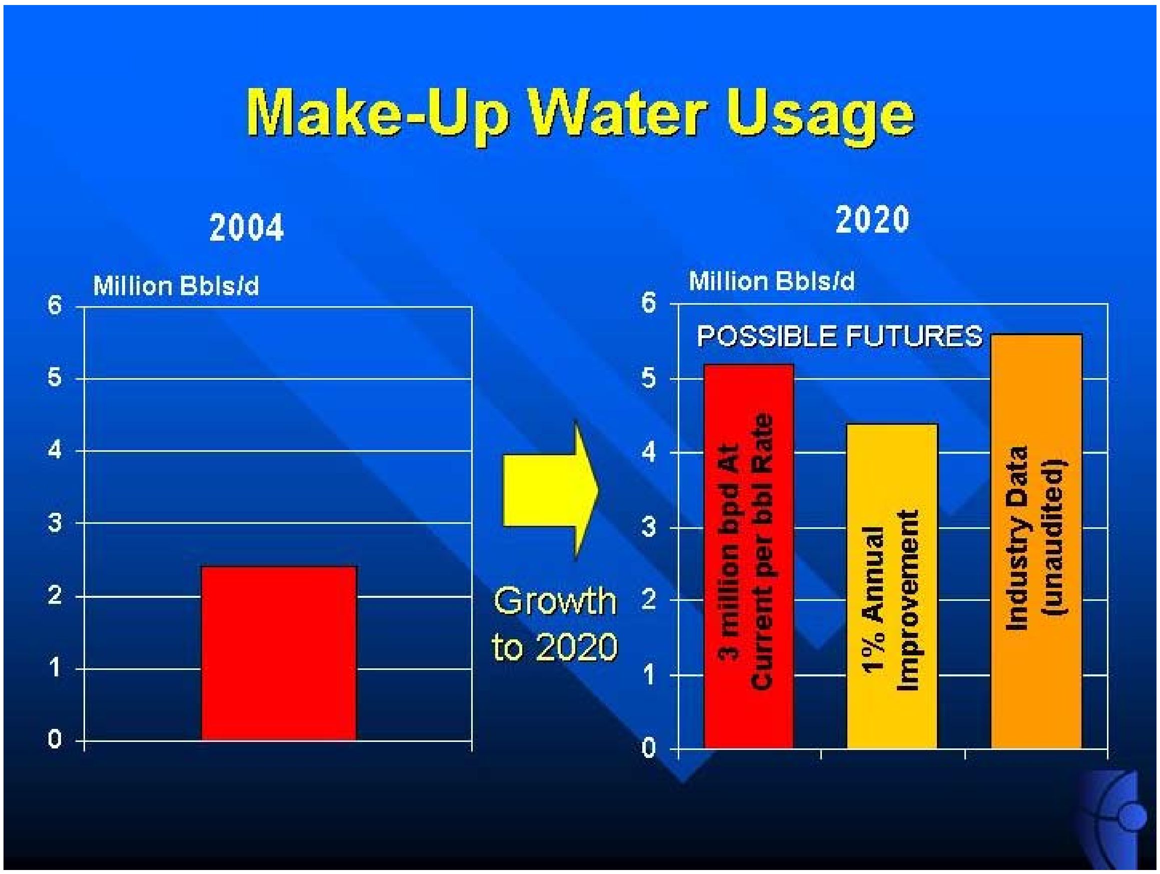


Source: ADOE 2004

Water Usage

Water usage is also an area presenting a challenge for the development of oil sands. As shown on Figure 5, in 2004 approximately 2.4 million barrels of water per day are consumed in oil sands production. Industry growth to 2020 would increase water consumption to over 5 million barrels per day.

Figure 5 - Make-Up Water Usage in the Oil Sands Industry

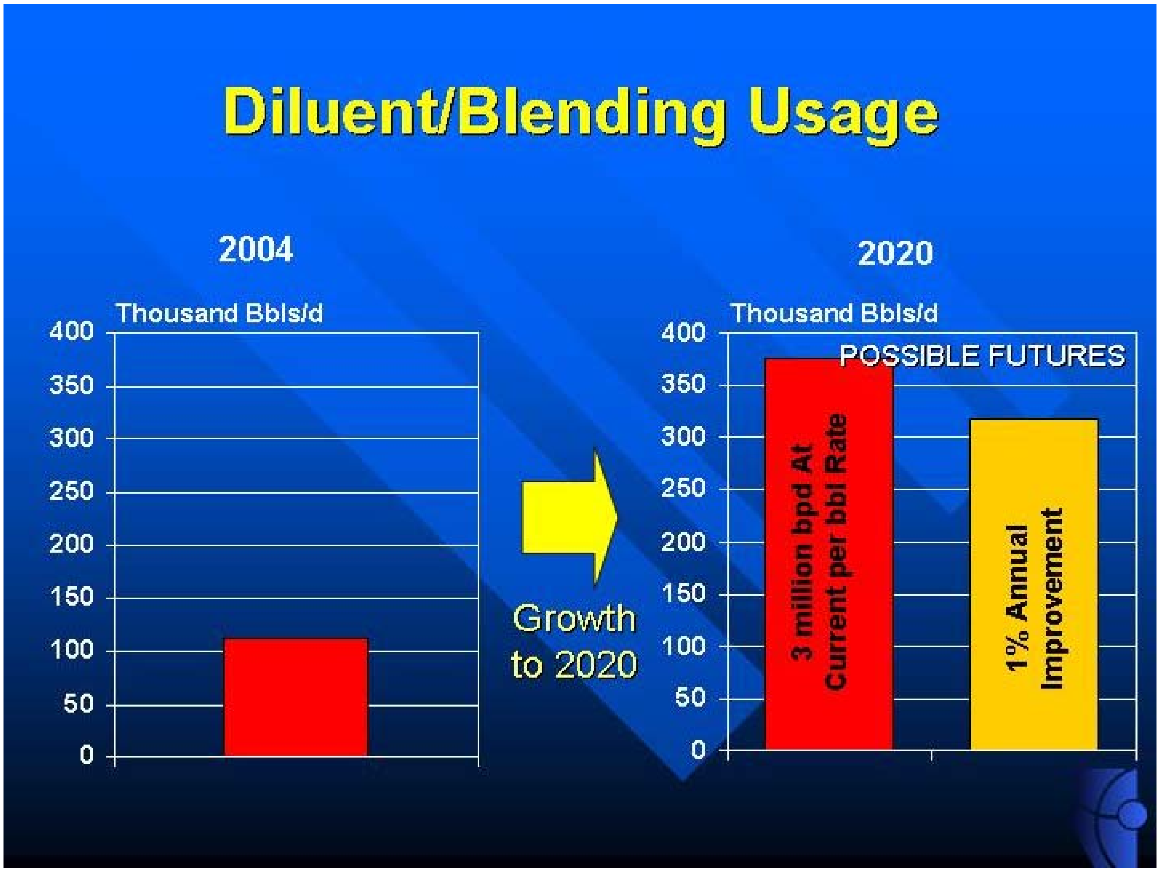


Source: ADOE 2004

Diluent Usage

Finally, diluent is required to enable shipment of bitumen by pipeline. In 2004 diluent usage was just less than 100,000 barrels per day. By 2020, diluent usage is forecasted to increase to close to 250,000 barrels per day. Challenges in the areas of natural gas, water and diluent usage will require new technologies to be developed that are less intensive in these commodities.

Figure 6 - Condensate Diluent Usage in the Oil Sands Industry



Source: ADOE 2004

Inventory of Oil Sands Research and Development

Information about the extent and intent of oil sands research was obtained from funding organizations as well as providers of research services. In most cases, this information was available on a project by a project basis for the five years covered by this inventory. Each project was reviewed and characterized according to categories and parameters designed to aggregate the information in a manner supportive of strategy and policy development. In two cases, the surveyed organization chose to provide a summary of their research effort classified according to the same categories and parameters.

While the focus of the study was oil sands, heavy oil was also included in the survey because technology developed for heavy oil can, and is, also applied to bitumen. For example, the VAPEX recovery technology is currently undergoing demonstration trials in bitumen reservoirs as well as in heavy oil reservoirs. SAGD technology is an initial recovery technology for bitumen, but it is also considered for use as a follow-up method in heavy oil reservoirs.

R&D projects were assigned to the following categories:

- *Research stage*
- *Life cycle stage*
- *Major reservoir type*
- *Improvement opportunity*

Research Stage

R&D spans the range from fundamental research aimed at knowledge creation to market research designed to establish current and future market needs. Applied research is intended to apply fundamental knowledge to specific technical challenges. Demonstration is the critical step where new technology is taken out of the laboratory and evaluated under realistic field conditions. Commercialization includes the activities required for the first commercial facilities. Market research is concerned with obtaining market information regarding current and future products. No government funded market research projects were found by this study, possibly indicating a need for future work. With respect to the Research Stage category, projects in this inventory were assigned to one of the following stages:

- *Fundamental*

  Fundamental research is aimed at creating new scientific knowledge and at understanding basic principles and relationships. Universities are major contributors to fundamental research.

- *Applied Research*

Applied research is concerned with the application of science to current and future challenges faced by society and industry. Industry and government laboratories such as ARC and NCUT conduct a significant amount of applied research.

- *Demonstration*

  Science and engineering based solutions developed in the laboratory need to be demonstrated in the field under small scale conditions that replicate commercial operations as closely as possible. Demonstration is necessary before significant capital can be approved for commercial facilities.

- *Commercialization*

  Commercialization activities involve studies, testing and evaluation required to establish competitive position (opposite competitive offerings), market position (with respect to market needs), environmental impact, safety and manufacturing reliability and costs.

- *Market Research*

  The business plan supporting the approval of commercial facilities is generally based on targeted market studies aimed at forecasting prices, costs and profit in order to calculate the return on investment of future earnings, often using a range of scenarios. In general, universities and government laboratories do not conduct market research.

Life Cycle Stage

Research projects were also characterised by their life cycle stage or the step in the cradle to grave development of the natural resource. Oil sand deposits are first exploited by applying a certain initial technology to the recovery of oil from the reservoir. Depending on the technology used, the extent of recovery varies from 5% for primary production alone to upwards of 80% for mining technologies. In cases where the initial recovery method yielded a relatively low rate of recovery, the opportunity exists to apply a second method as a follow-up technique to recover additional oil from the reservoir. The third step in the oil sands value chain involves upgrading bitumen into synthetic crude oil and transportation fuels. All along the value chain it is of paramount importance to consider environmental impact to air, water and soil. Of particular importance is the eventual remediation and reclamation of the land at the end of reserve life. Research projects were therefore classified as to which step in the life cycle they applied to:

- *Recovery*
- *Follow-up*
- *Upgrading*
- *Environmental – Air Quality*
- *Environmental – Water Quality*
- *Remediation and Reclamation*

Major Reservoir Types

As discussed earlier in this report of an effort was made to define the major types of oil sands reservoirs. This was a collaborative effort with Alberta Department of Energy and the Energy and Utilities Board. It became quickly apparent that a much larger effort will be required to adequately document the relevant technical characteristics of oil sand reservoirs. Because of the heterogeneous nature of the resource, the vast majority of reservoirs contain at least one fault in addition to their major defining feature. The task of documenting and cataloguing the combinations of features and faults occurring in Alberta oil sands reservoirs is a large one particularly when in-place bitumen volumes need to be associated with each category and subcategory of reservoir. In this study, where appropriate, research projects were assigned to one or more of the following major reservoir types, which described earlier in Tables 3 and 4:

- *Mineable*
- *Current SAGD and CSS*
- *Primary Production*
- *Thinner than Current SAGD and CSS*
- *Shallower Depth than Current SAGD and CSS*
- *Bitumen in Carbonates*

Improvement Opportunity

As described earlier in this report, the industry is facing significant challenges for the continued economic development of reservoirs for which recovery technology already exists. Concerns about use of natural gas, water and diluent may threaten the extent of oil sands development in the future. From the point of view of R&D, these challenges represent opportunities for improvements. R&D projects were therefore reviewed and assigned to one or more improvement category when they targeted such improvements:

- *Reduced Energy Intensity:*

  Increased energy consumption by oil sands projects is likely to increase the price and reduce exports of natural gas. Technologies than reduce the energy intensity of oil sands exploitation are of strategic importance.

- *Reduced Water Use*

  Water usage is also an area presenting a challenge for the development of the oil sands. Water is a critical and limited resource in Alberta. Technologies that reduce the use of water by the oil sands industry offer strategic value.

- *Low Pressure Reservoirs*

  A significant amount of reservoirs either lack the pressure required for exploitation or have been pressure depleted by initial exploitation. A requirement exists for technologies that economically re-pressurize reservoirs or that permit their exploitation under low pressure conditions.

- *Reduced Need for Diluent*

  Transporting crude bitumen by pipeline requires NGL or LPG as a diluent in order to reduce oil viscosity to pipeline specification. Forecasted increases in crude bitumen production are likely to cause a shortage of diluent. New technologies that reduce the need for diluent are therefore required.

- *Handling Reservoir Water*

  The presence of water in or in the vicinity of an oil sands formation often causes problems that reduce the economic value of a reservoir. Exploitation technologies viable in the presence of water would increase the economic attractiveness of the oil sands.

- *Reduced Losses to Thief Zones*

  Some zones inside an oil sands reservoir will consume energy without contributing to oil production, thereby causing higher levels of energy consumption than what would be otherwise required. Technologies to seal or isolate thief zones are likely to be of significant value.

- *Methods to Deal with Shale Zones*

  The presence of shale zones tends to disrupt and reduce the economic value of an oil sands reservoir. Technologies to deal with shale zones are needed to increase the economic value of oil sands exploitation.

Overall Results

Total funding for bitumen and heavy oil R&D was approximately $117 million in the five years from fiscal 1998-99 to fiscal 2002-03. As shown on Table 5, the funding organizations that provided the most funds were by a wide margin Natural Resources Canada (NRCan) and the Alberta Energy Research Institute (AERI). NRCan funding was almost exclusively directed to the operations of the laboratories and pilot plants located in Devon Alberta. AERI, by contrast funded a broad mix of targeted projects from fundamental research to commercialization performed by several facilities and sites.

Funding to universities was mostly through programs such as the Canada Foundation for Innovation, Canada Research Chairs, NSERC and programs administered by Alberta University Research and Strategic Investments. In aggregate, these funding agencies provided approximately $23 million over 5 years, primarily to universities. These funding programs support the infrastructure needs of universities as well as research chairs. These types of projects are often of a very broad scope and are applied to more than one industry. In several cases, a percent allocation to oil sands research was applied to the total funding amount to adequately reflect the amount of funding directed at oil sands. This percent allocation was obtained by discussion with the principal investigator at the university. This allowed the development of an accurate estimate of the amount of funding directed at oil sands research. However, it does underestimate the extent of infrastructure and intellectual capital available in the future for oil sands research because the facilities and staff, once in place, can be applied to new research objectives. For example, facilities and staff that were funded for conventional petroleum research were not included in this inventory but, in the future, they could apply their skills, knowledge and equipment to oil sands challenges.

Table 5 – Total Oil Sands Research Funding (1998-99 to 2002-03)	
AERI COURSE	$5,122,464
AERI Industry Research Program	$16,823,446
AERI NCUT	$2,997,230
AERI AACI	$5,704,511
TOTAL Alberta Energy Research Institute	$30,647,651
NRCan NCUT	$27,963,621
NRCan CANMET	$18,696,000
TOTAL Natural Resources Canada	$46,659,621
CFI	$7,946,694
CRC	$700,000
NSERC	$8,106,614
URSI/ASRIP	$6,370,269
ARC	$7,860,367
AIF	$246,000
TPC	$1,667,000
Other Government	$7,408,894
TOTAL	$117,613,110

Public funds provided for oil sand R&D were spent by research organizations equipped with the laboratories and pilot plants required to conduct research. Table 6 lists the major centers where oil sand R&D was conducted. At the top of the list is the National Center for Upgrading Technology in Devon, Alberta which is a federal-provincial partnership and receives funds from NRCan, AERI, ARC, as well as other government sources. This facility is dedicated to research into the upgrading of bitumen and heavy oil into synthetic crude oil and transportation fuels such as gasoline, diesel and jet fuel. Second on the list is the associated federal CANMET facility in Devon. This center is funded by NRCan and industry. It conducts research on advanced separation technologies related to petroleum.

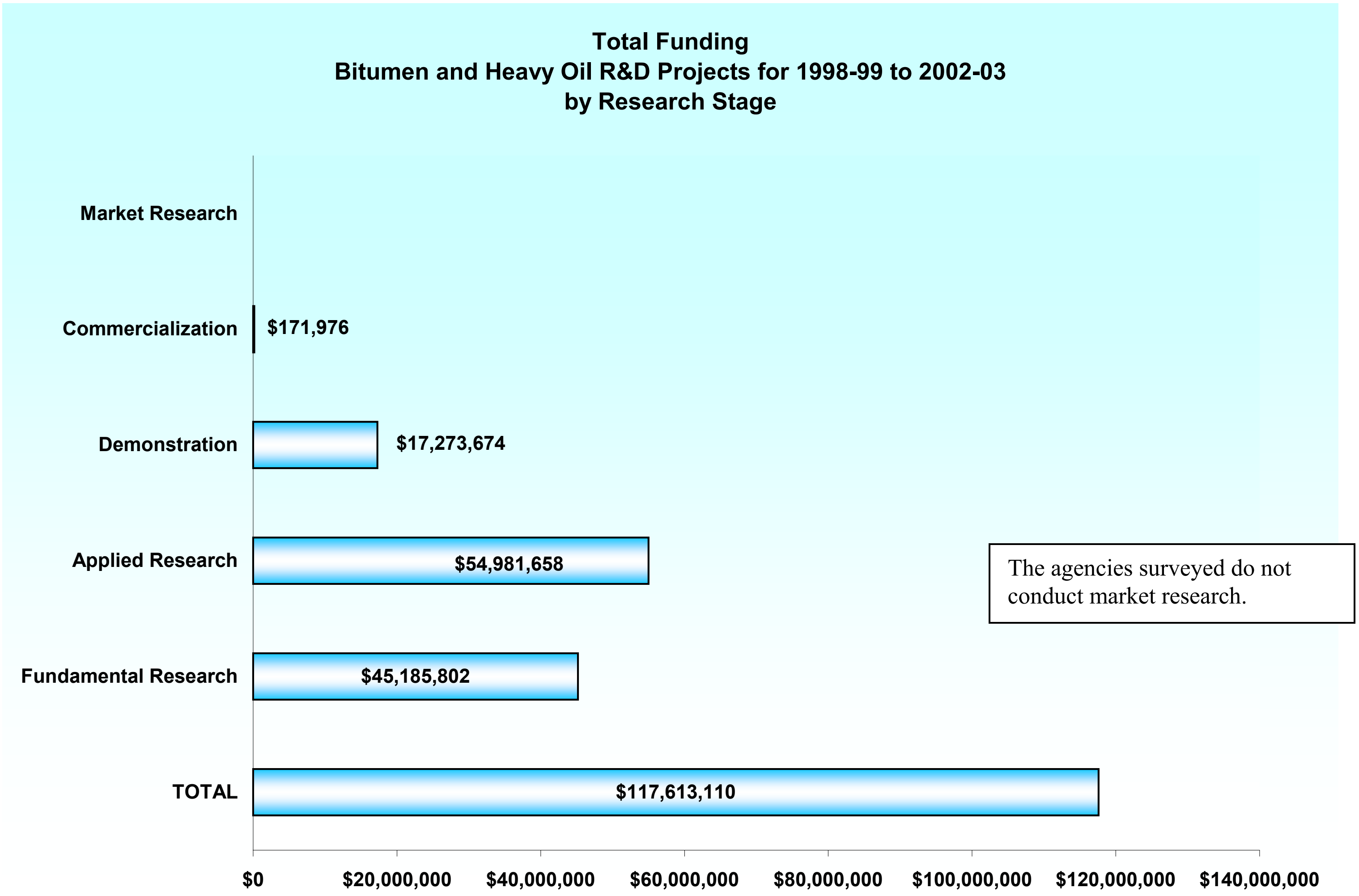
The University of Alberta, the Alberta Research Council and the University of Calgary each spent approximately $12 million over five years for bitumen and heavy oil research.

Table 6 – Total Oil Sands Research Providers (1998-99 to 2002-03)	
National Centre for Upgrading Technology (NCUT)	$38,882,866
CANMET CETC - Devon	$18,696,000
Alberta Research Council	$12,205,556
University of Alberta	$12,723,744
University of Calgary	$11,379,199
Saskatchewan Research Council	$1,442,735
Others (Field demonstration sites and Canadian universities)	$22,283,010
TOTAL	$117,613,110

Analysis by Research Stage

Figure 7 shows the distribution of total oil sands R&D by research stage. The largest category is applied research and reflects the substantial amount of work conducted by NCUT and ARC. The next category is fundamental research which is conducted mostly by universities. It is important to note the relatively small amount spent on demonstration trials. For fundamental and applied research to be commercialized and to produce an economic impact, it is necessary to demonstrate it at a pre-commercial scale. Without successful demonstration under field conditions, major new technologies are unlikely to be commercialized because they would place significant capital investments in new plants and facilities under excessive technology risk. Therefore, the information on Figure 7 appears to indicate that a large amount of technology developed in the laboratory will not be commercialized because of insufficient investment in demonstration trials. However, anecdotal information indicates that some demonstration trials are proceeding in Alberta and Saskatchewan without support from public funds. Major companies such as Nexen and EnCana seem to be able to undertake alone or with private sector partners selected demonstration trials needed by their strategy. In order to draw conclusions and policy recommendations it would therefore be important to conduct a survey of privately funded research and demonstration trials in order to construct the complete picture on oil sands R&D. Anecdotal information indicates that government funding is prominent in the early stages of research, particularly at the fundamental and applied stages. Corporate funding on the other hand would become prominent in the demonstration and commercialization stages.

Figure 7 – Total Bitumen and Heavy Oil Research by Research Stage



Analysis by Life Cycle Stage

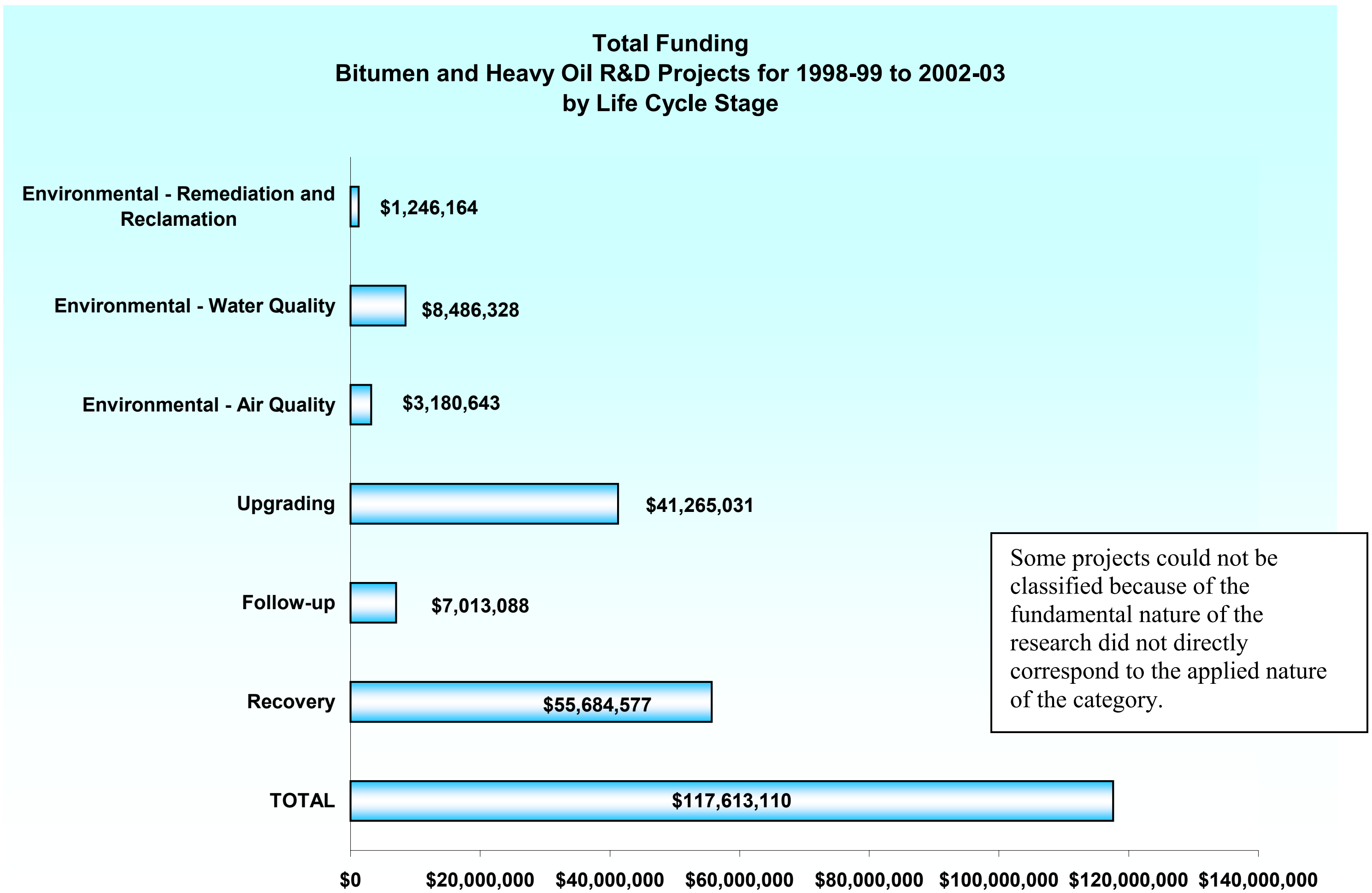
The determination of the life cycle stage targeted by a research project (whether: recovery, follow-up, upgrading and/or environmental) is far from being a simple matter. On the one hand, some fundamental research projects could not be classified in this manner. This is because of the fundamental nature of the research and the applied nature of the category. Fundamental research has as primary objective the creation of knowledge rather than the solving of a problem. The applied nature of the life cycle category made it inappropriate to classify some fundamental research projects. On the other hand, some applied research and demonstration projects are intended to have useful applications in more than one life cycle stage. For example, some technology improvements could be applied to both initial recovery and follow-up. SAGD is used for the initial recovery of bitumen but is also being investigated as a follow-up method after cold production. In the heavy oil and bitumen segment the term follow-up is used to designate a recovery method used after the initial recovery method. Follow-up is generally analogous to secondary and tertiary recovery in the conventional oil segment. However, follow-up generally implied a complete change to the recovery method while secondary or tertiary recovery generally involves enhancements to the primary recovery method.

As shown on Figure 8, recovery was the stage that attracted the most funding. A relatively small amount was spent on follow-up research. This relationship is reasonable given the fact that oil sands development are at an early stage. The exploitation of oil sands deposits on a significant scale is only just beginning and most of the attention is on initial recovery methods. However, at some point in the future, follow-up methods will become required.

Upgrading attracted the second most important level of funding. This is due in a large part to the research conducted at the National Center for Upgrading Technology.

It is important to note that the lowest level of funding was directed at research conducted on environmental issues. The aggregate amount of funds spent on environmental research was slightly more than 10% of the total amount spent on oil sands research. This percentage is small considering the importance of cradle to grave management of natural resources, particularly when exploitation has the potential to result in significant environmental impact. Increasing the percentage of research dedicated to environmental issues would certainly improve the alignment of energy R&D with the expectations of a broad group of stakeholders. In particular, it is worth pointing out that the smallest amount was spent on environmental issues related to remediation and reclamation. It should be clear that more needs to be done in this area because of the requirement for remediation and reclamation of land after oil sands have been exploited. This is particularly important for mineable deposits.

Figure 8 – Total Bitumen and Heavy Oil Research by Life Cycle Stage



Analysis by Major Reservoir Type

As it was the case for life cycle stages, fundamental research projects were often not targeted at any specific reservoir type. In addition, all upgrading work is applicable to bitumen and heavy oil from any reservoir and is not targeted at any specific reservoir type. In these cases, projects were not assigned to a reservoir type. By contrast, some recovery technologies such as vapour recovery technologies (e.g.: VAPEX) are applicable to more than one reservoir type. For example, in this study, research projects related to VAPEX and other similar methods were assigned to the following reservoir types:

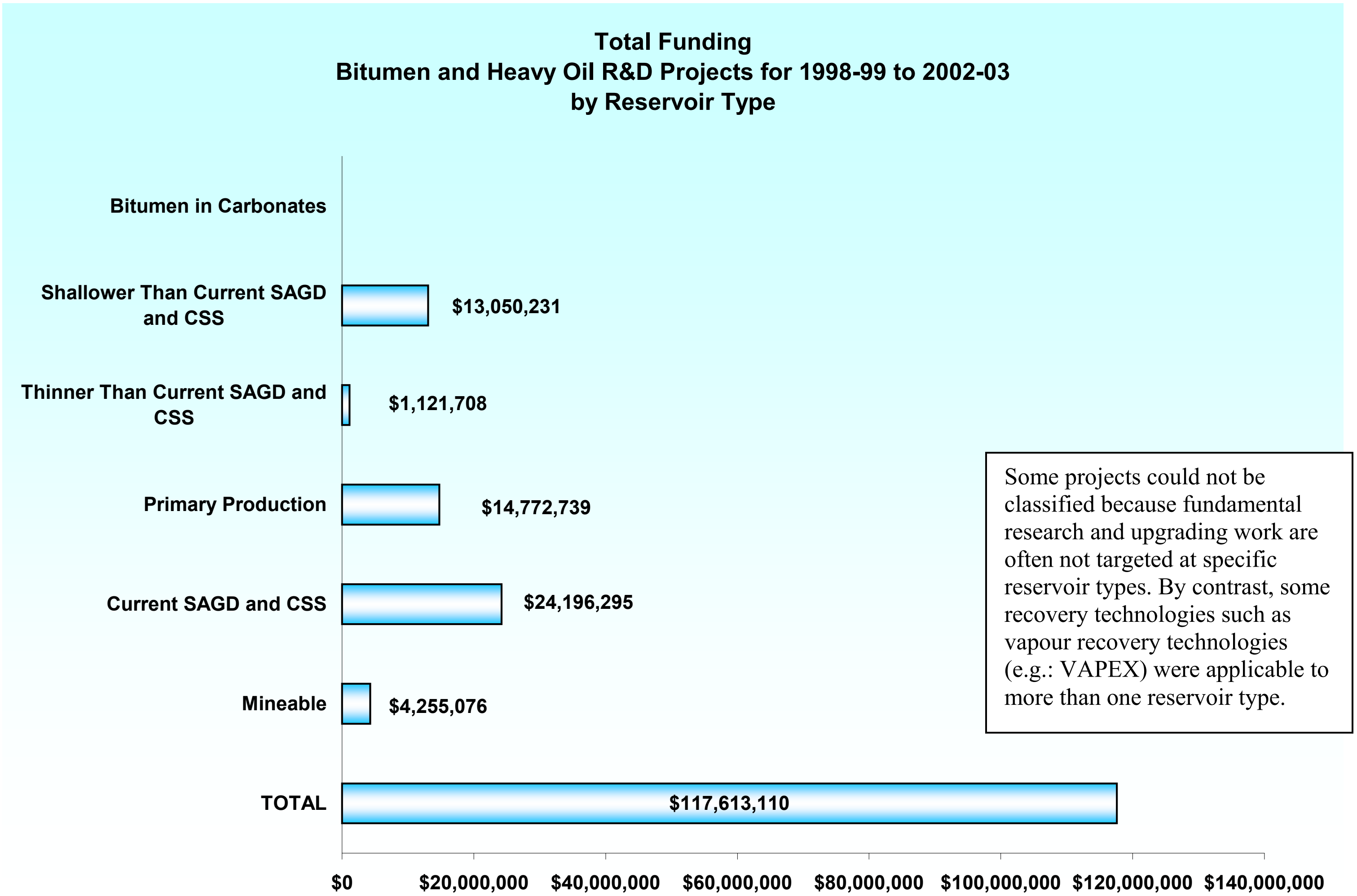
- Current SAGD and CSS
- Primary production (as follow-up methods)
- Shallow reservoir type

In-situ combustion methods were thought to have applicability to thin reservoirs.

As shown on Figure 9, the reservoir type that attracted the most funding was "Current SAGD and CSS". This is not surprising given the large size of this reservoir type. The fact that a significant amount of research was conducted on vapour recovery technologies resulted in important amounts of funding being assigned to shallow and primary production reservoir types. Very little work appears to have been directed at thin reservoirs. No projects could be identified that targeted bitumen in carbonate reservoirs.

Most of the research appears to be directed at improving the economy to efficiency of existing or near commercial technologies directed at the reservoir types that are presently the object of active development. A much lower level of funding was targeted at marginal reservoirs that would need to be developed in the future in order to maintain the economic contribution that oil sands are making to the Alberta economy.

Figure 9 – Total Bitumen and Heavy Oil Research by Major Reservoir Type



Analysis by Improvement Opportunity

Many research projects, in particular fundamental research projects, would have the potential to become applicable to an improvement opportunity of importance to the industry. However, in order to be classified into an improvement category in this study, the project had to be targeted at or justified by the improvement opportunity rather than simply having the potential to make a contribution. Therefore, many fundamental research projects were not assigned to any improvement category because they were not designed as problem-solving projects. On the other hand, vapour and in situ combustion recovery methods were assigned to more than one category because the impetus for their development arise from the fact that they require less energy, less water and would be applicable to low-pressure reservoirs.

Figure 10 indicates that the improvement opportunity that attracted the most funding was "Reduced Energy Intensity". This is not surprising given the importance of energy costs, particularly natural gas usage, in the development of oil sands. By contrast, no projects could be assigned to the improvement areas related to thief zones and shale zones.

Analysis by Year

Figure 11 illustrates total funding for oil sands research by year for the past 5 years. The data does not indicate a pattern of increasing or decreasing funding over this time period. Fluctuation in the year-to-year level of funding is to be expected because many funding programs are of a competitive nature where oil sands research projects compete with research projects from other industries.

Figure 10 – Total Bitumen and Heavy Oil Research by Improvement Opportunity

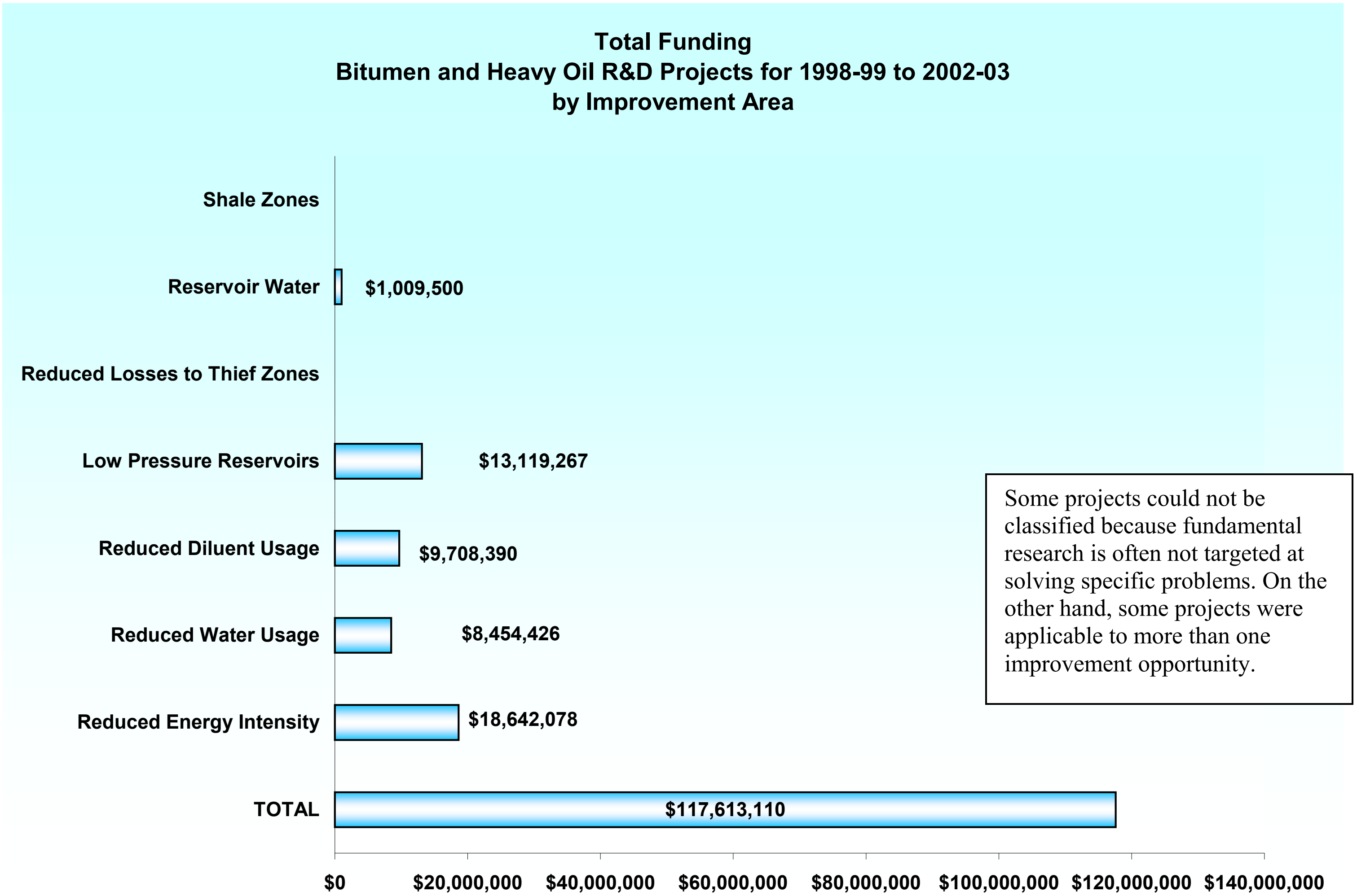
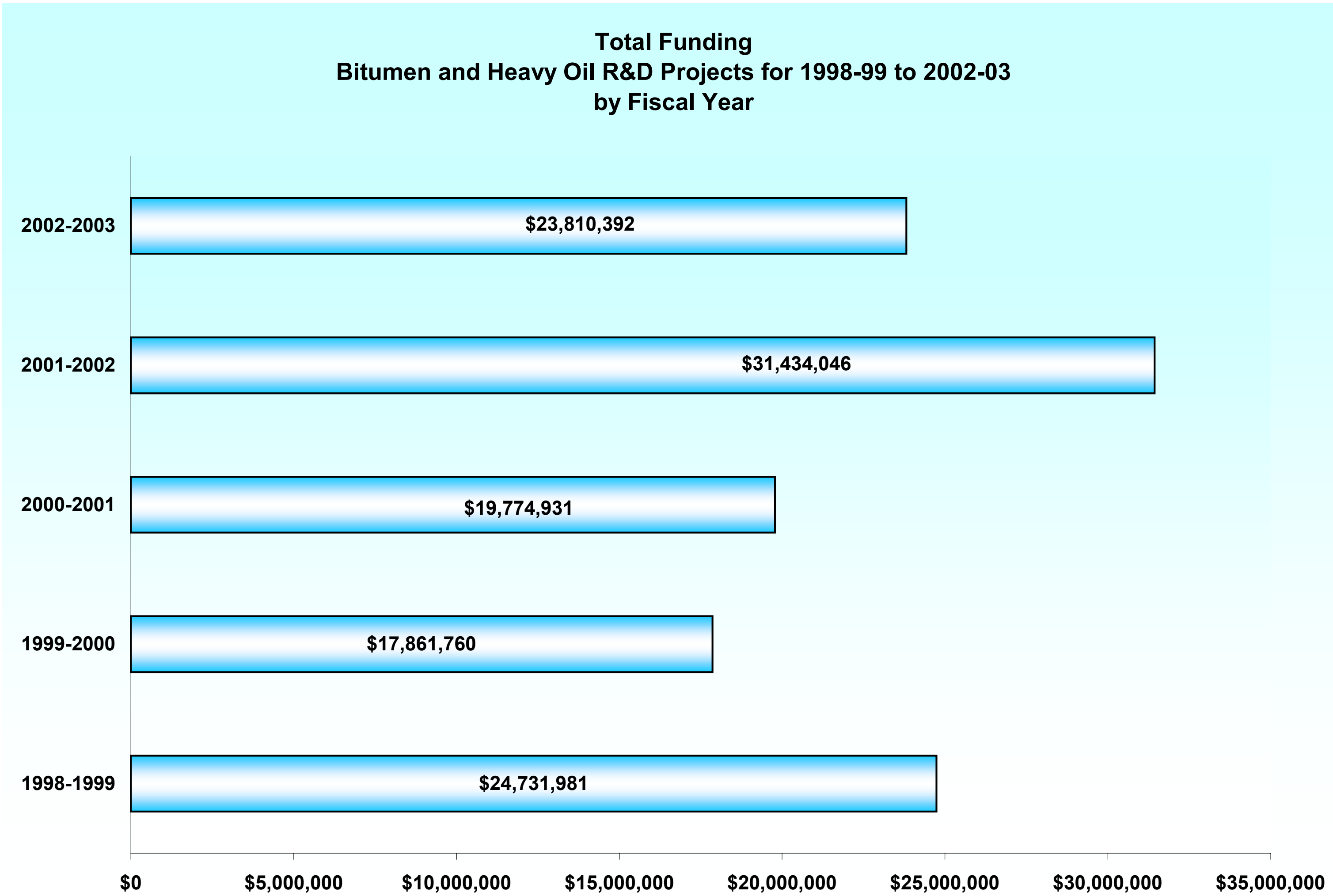


Figure 11 – Total Bitumen and Heavy Oil Research by Year



Review of Funding Programs

AERI COURSE

The Alberta Energy Research Institute (AERI) funds university research primarily through its program called Core University Research in Sustainable Energy (COURSE). This program provides a link between universities and the energy industry and funds basic research in strategic areas. In partnership with industry COURSE, identifies industry needs. Then, proposals are sought from university researchers to perform the required work. A review panel composed of representatives from industry, university and AERI evaluates these proposals and selects the most promising and relevant projects. Since inception in 1999, COURSE has provided $9.25 million in provincial funding to 70 projects in fundamental energy research.

Over the five years covered by this study, the COURSE program funded $5.1 million of oil sands and heavy oil related research. The analysis of these COURSE bitumen and heavy oil projects is shown on Figures 12 to 15. All the funding provided by COURSE was directed at fundamental research conducted in Alberta universities. While some of the projects funded by COURSE pertained to environmental issues, upgrading and follow-up, the majority of projects were concerned with recovery. Given the fundamental nature of COURSE projects, it is difficult to assign them to specific reservoir types and improvement areas. However some projects dealt with fundamental issues associated with VAPEX, SAGD and technologies used in mining oil sands. These projects were assigned to the reservoir types and to the improvement opportunities associated with the recovery technology.

Figure 12 – COURSE Bitumen and Heavy Oil Research by Research Stage

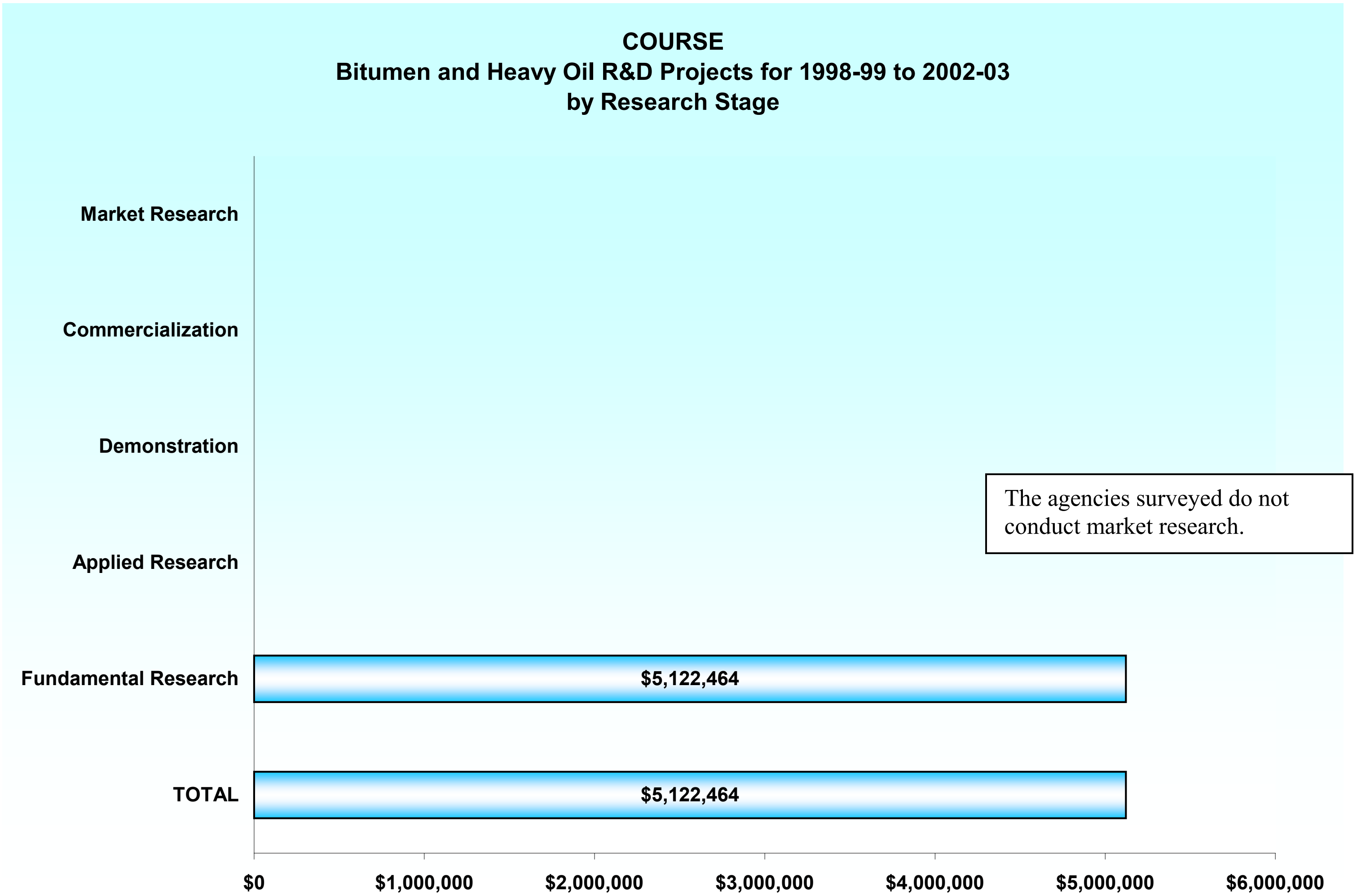


Figure 13 – COURSE Bitumen and Heavy Oil Research by Life Cycle Stage

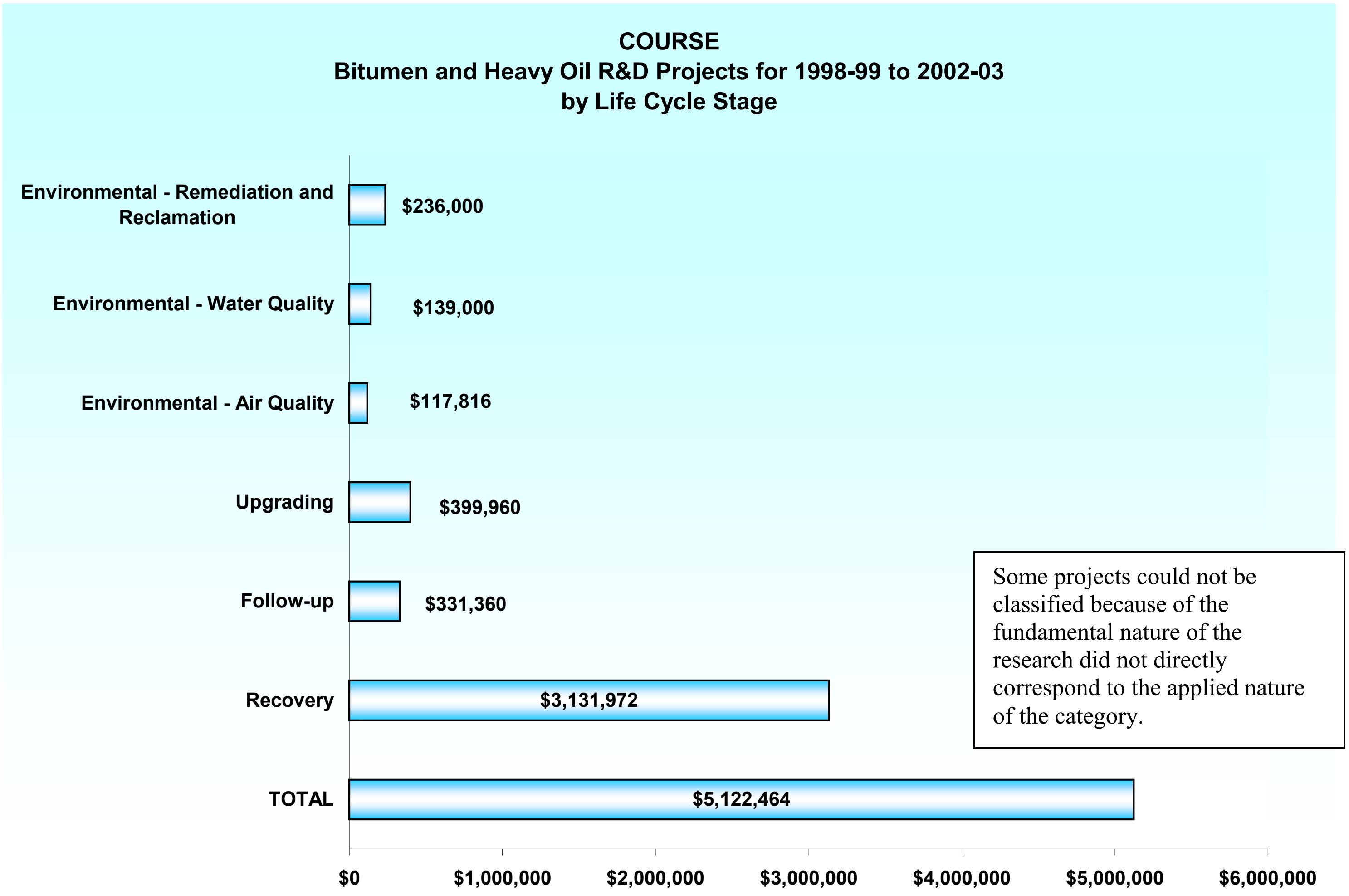
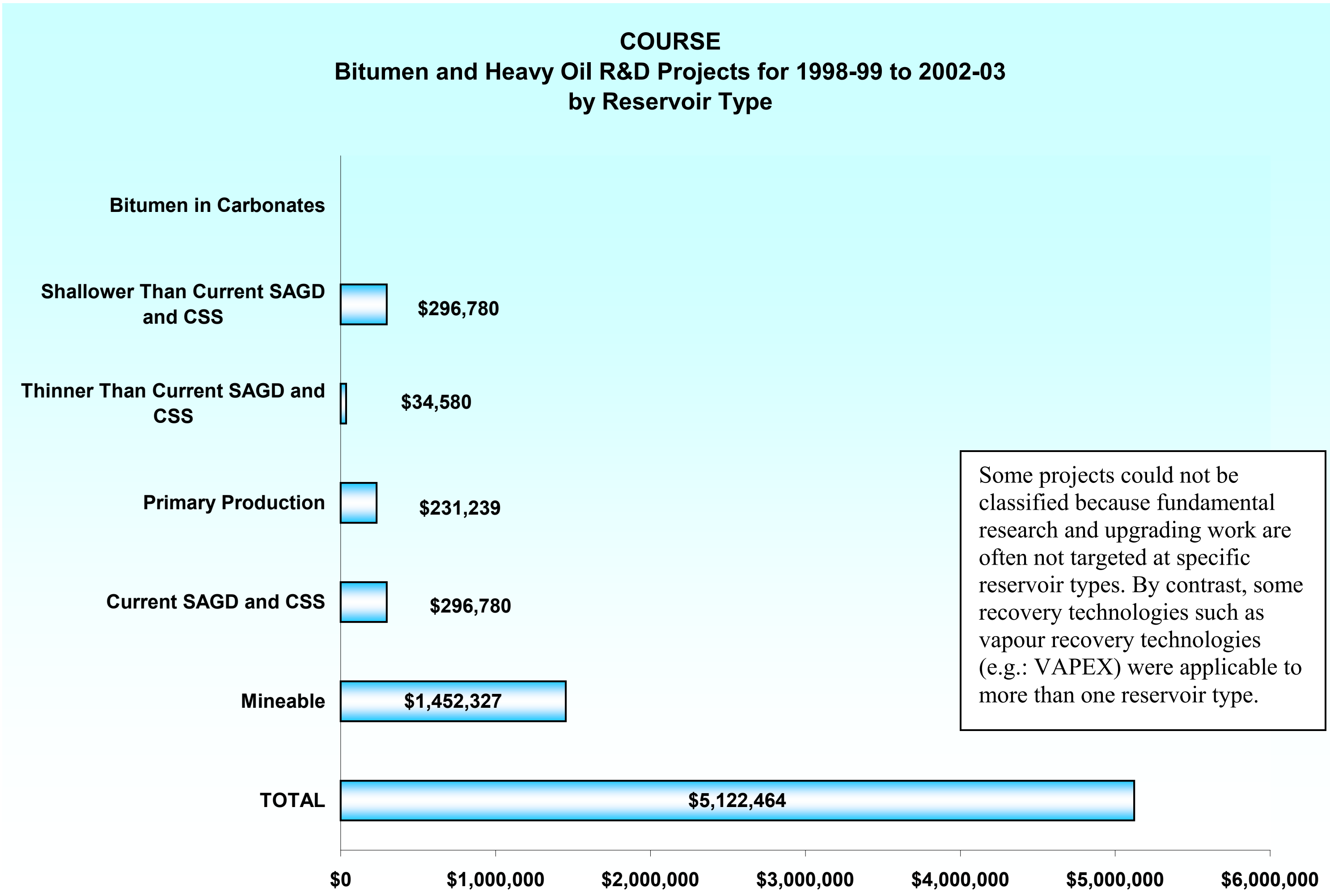
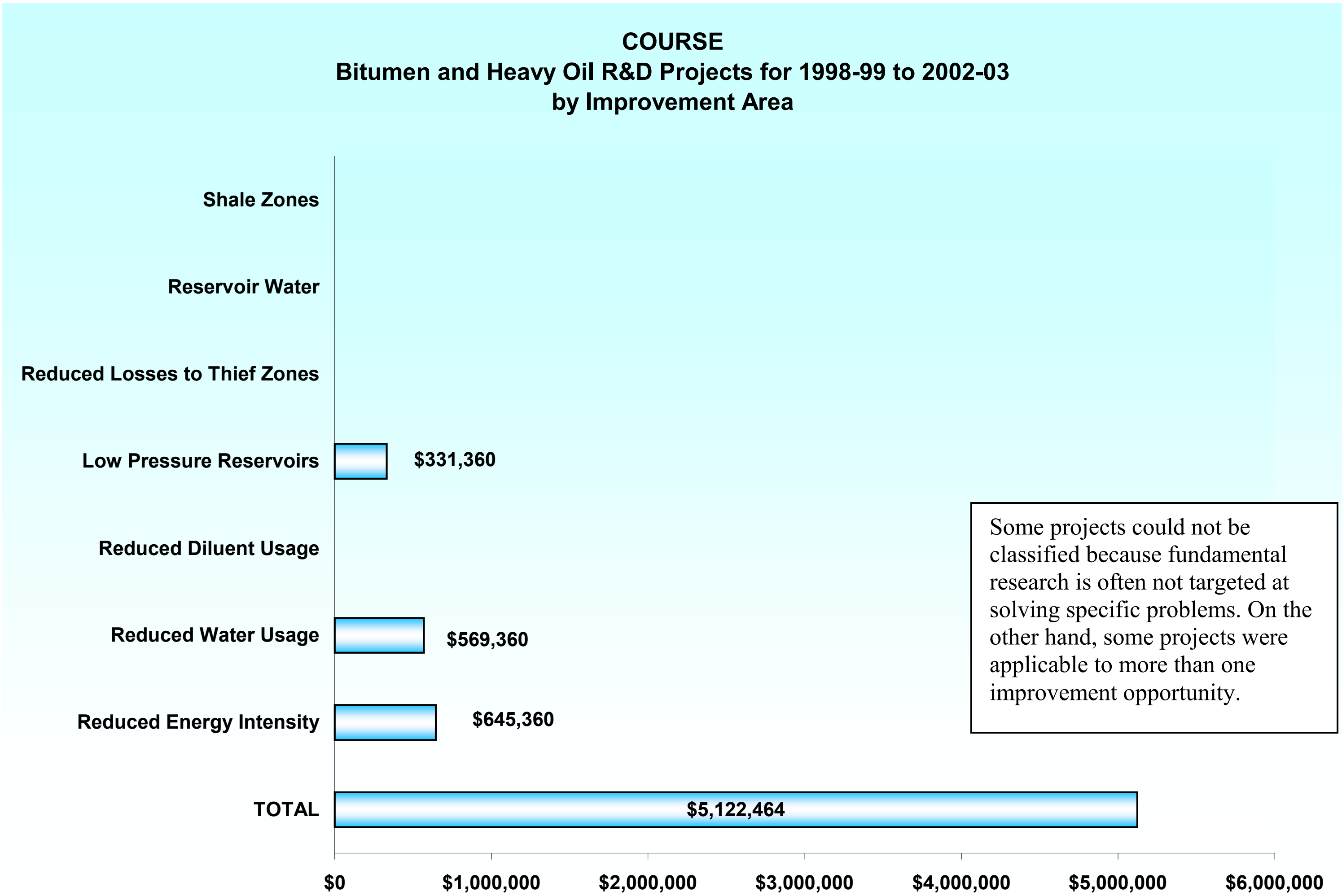


Figure 14 – COURSE Bitumen and Heavy Oil Research by Major Reservoir Type



Some projects could not be classified because fundamental research and upgrading work are often not targeted at specific reservoir types. By contrast, some recovery technologies such as vapour recovery technologies (e.g.: VAPEX) were applicable to more than one reservoir type.

Figure 15 – COURSE Bitumen and Heavy Oil Research by Improvement Opportunity



AERI Industry Research Program

AERI's Industry Research Program funds projects that are aligned with AERI's priority areas from fundamental research to technology commercialization. Eligible projects are those that are related to energy research & development and that are of strategic importance and commercial benefit to Alberta. Proposals are evaluated by a team using a matrix of 12 performance criteria that represent the values, priorities and expectations of AERI.

During the five years covered by this study, AERI's Industry Research Program funded $16.8 million of oil sands related projects. The analysis is presented on Figures 16 to 19. Over 90% of these projects were technology demonstration projects that targeted recovery challenges. SAGD and modifications of the SAGD process were prominent. Projects that aimed at reducing energy usage attracted $10.6 million in funding. The bitumen froth treatment demonstration pilot received $8.0 million from AERI and reduced the amount of diluent required to ship treated bitumen by pipeline.

Total AERI Funding for Bitumen and Heavy Oil Research and Demonstration

In addition to COURSE and the Industry Research Program, AERI provided funds to the National Center for Upgrading Technology (NCUT) and to the Alberta Research Council for the AERI-ARC Core Industry (AACI) program. Total funding by AERI for these four programs over the last five years amounted to $30.6 million. The analysis for total AERI funding is shown on Figures 20 to 23. Approximately half of the funding, or $15.4 million, was allocated to demonstration pilots. Applied research required $9.5 million while fundamental research $5.5 million. The vast majority of funding, or $24.6 million, was directed at recovery. Projects involving SAGD, modifications of SAGD and VAPEX were prominent and would be applicable to reservoir types that are exploitable with SAGD as well as shallow reservoirs. A large number of projects, or $12.9 million, were aimed at reducing energy requirements.

Figure 16 – AERI's Industry Research Program by Research Stage

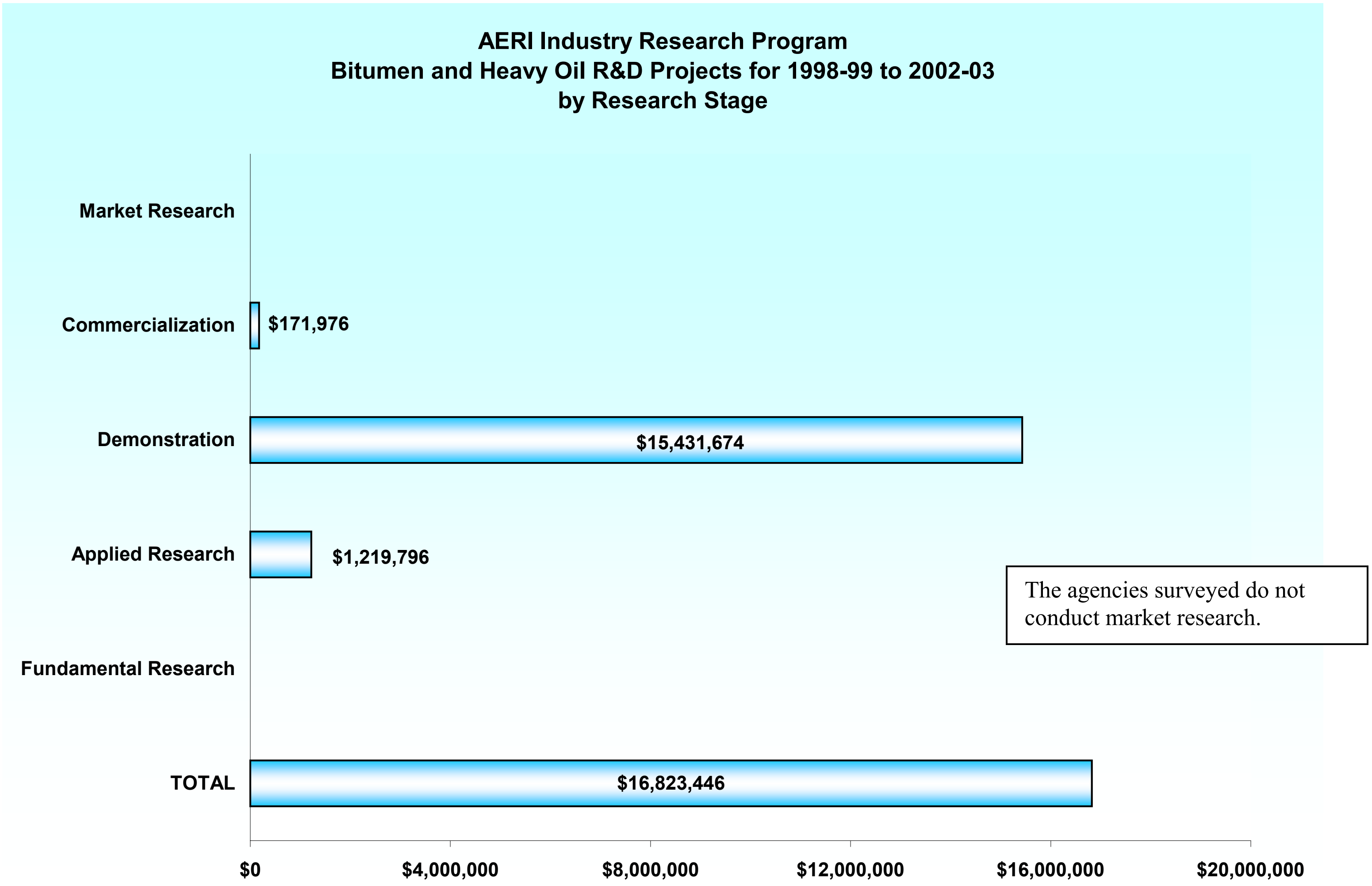
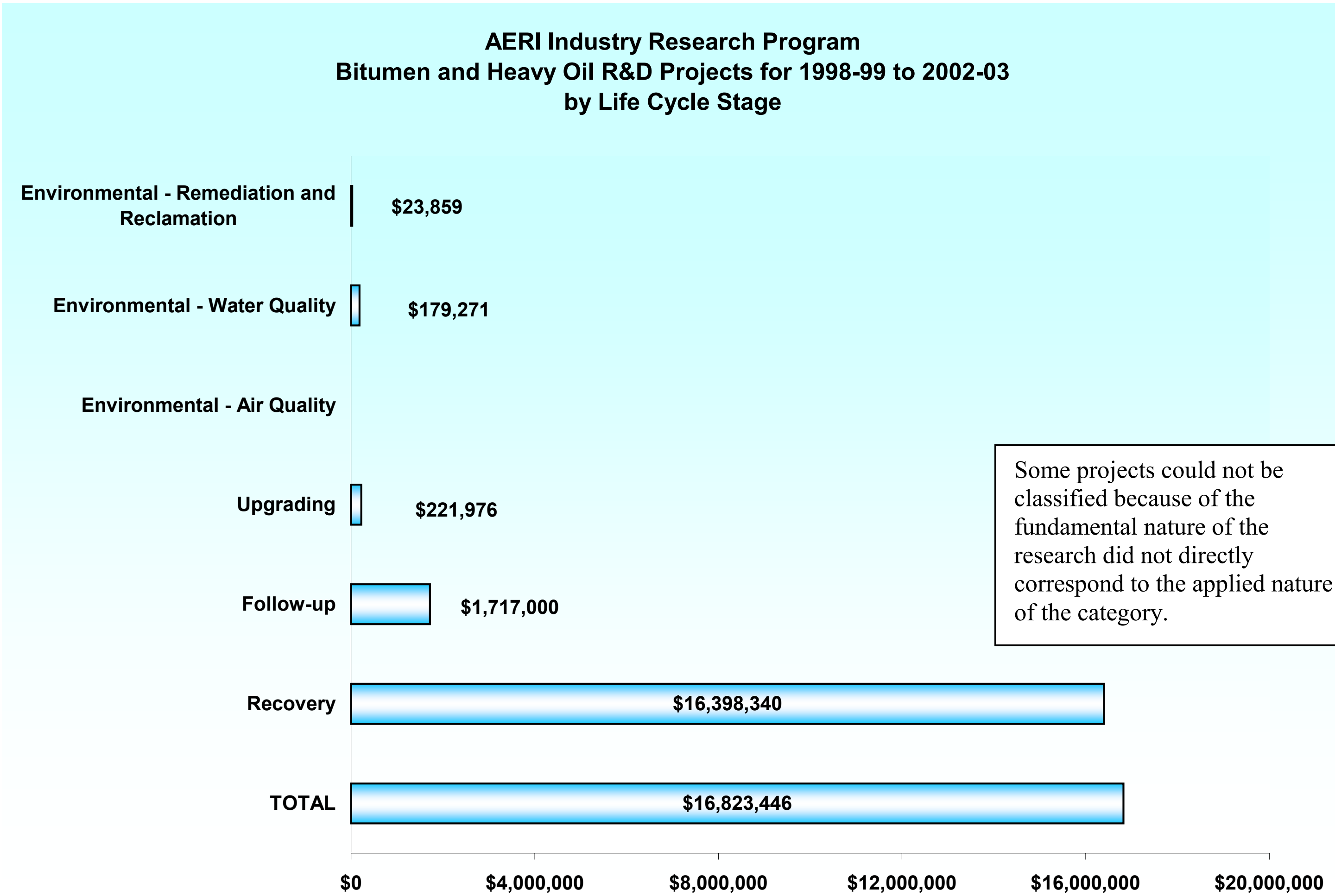


Figure 17 – AERI's Industry Research Program by Life Cycle Stage



Some projects could not be classified because of the fundamental nature of the research did not directly correspond to the applied nature of the category.

Figure 18 – AERI's Industry Research Program by Major Reservoir Type

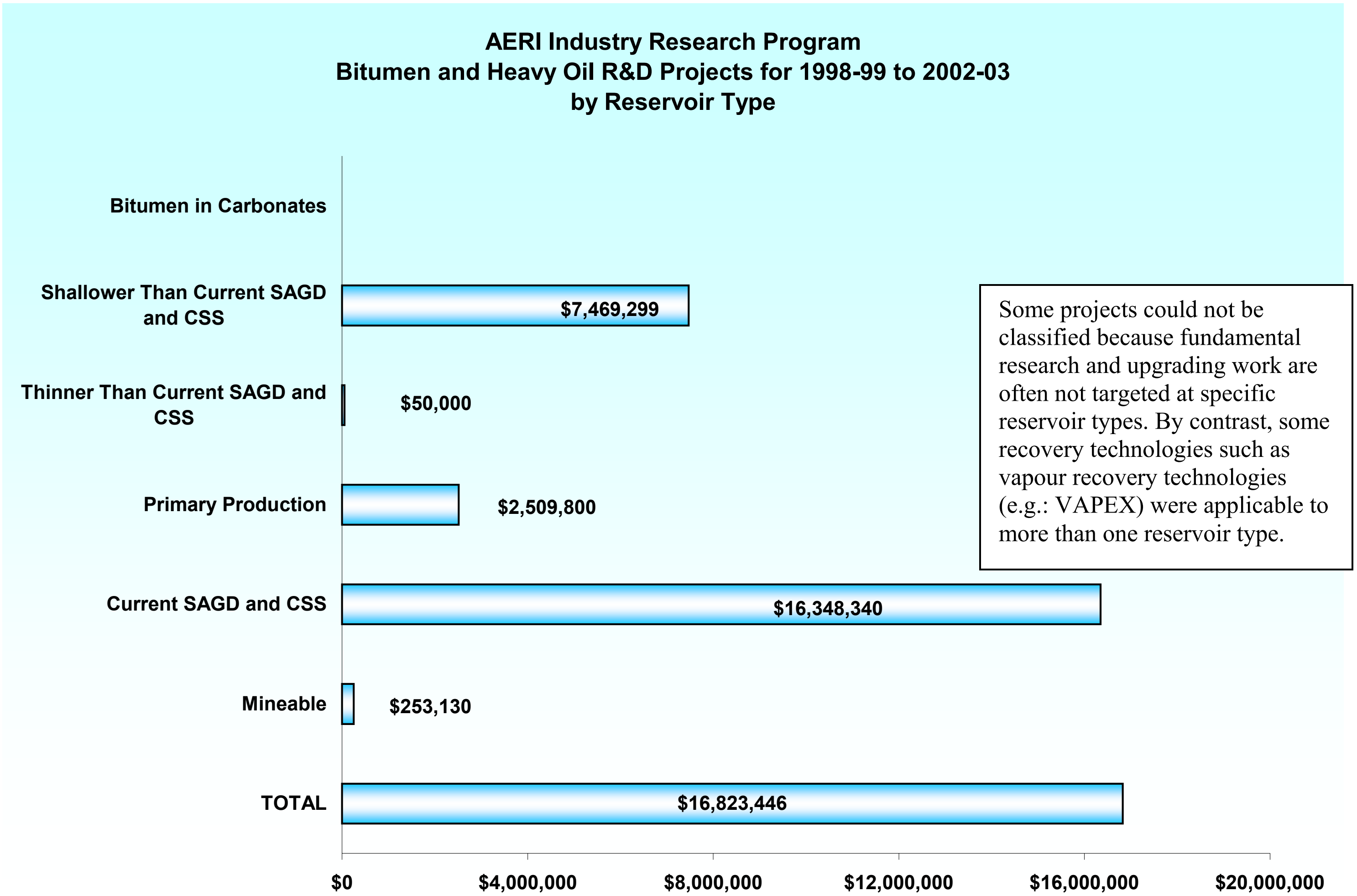
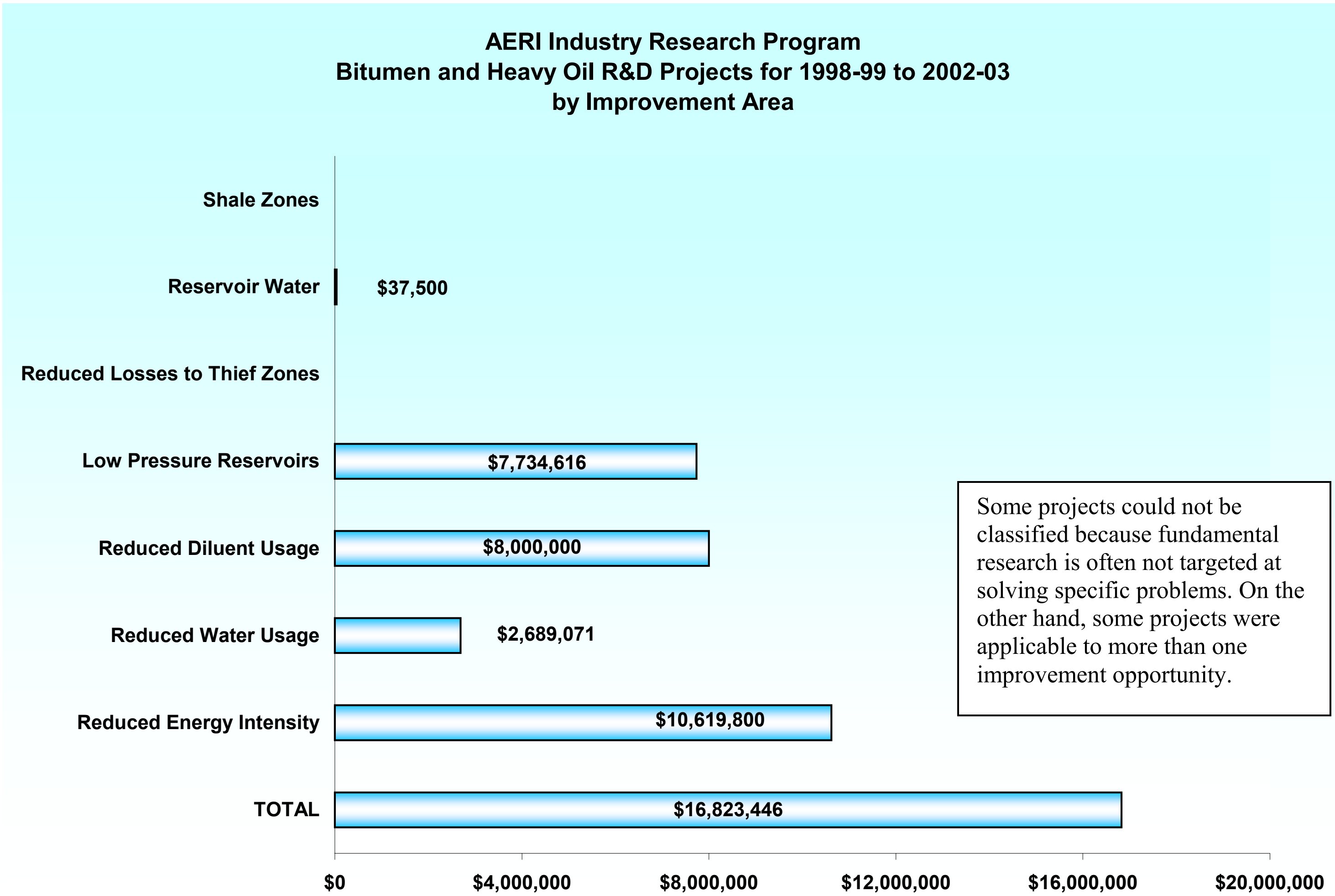


Figure 19 – AERI's Industry Research Program by Improvement Opportunity



Some projects could not be classified because fundamental research is often not targeted at solving specific problems. On the other hand, some projects were applicable to more than one improvement opportunity.

Figure 20 – Total AERI Bitumen and Heavy Oil Research by Research Stage

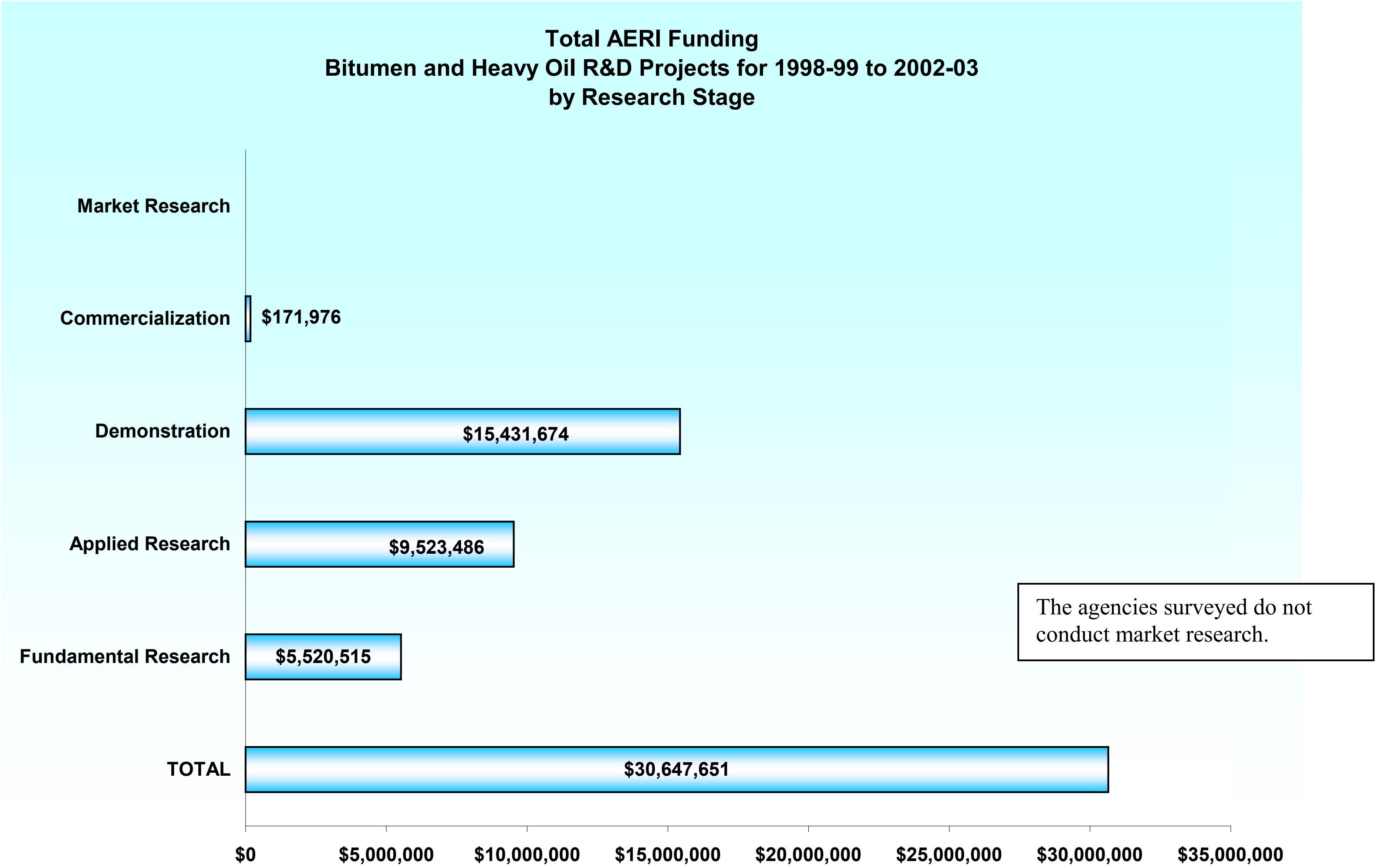


Figure 21 – Total AERI Bitumen and Heavy Oil Research by Life Cycle Stage

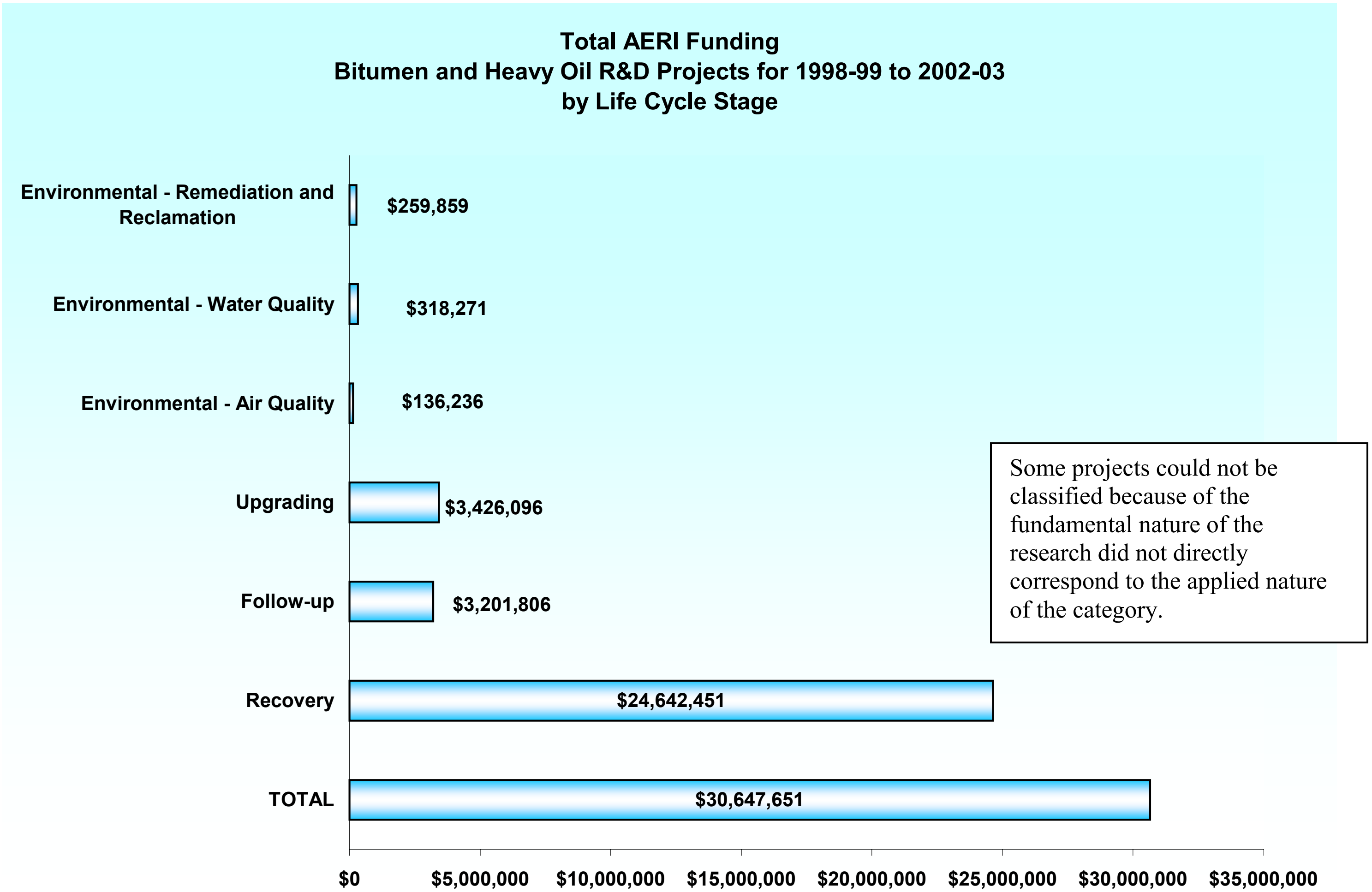
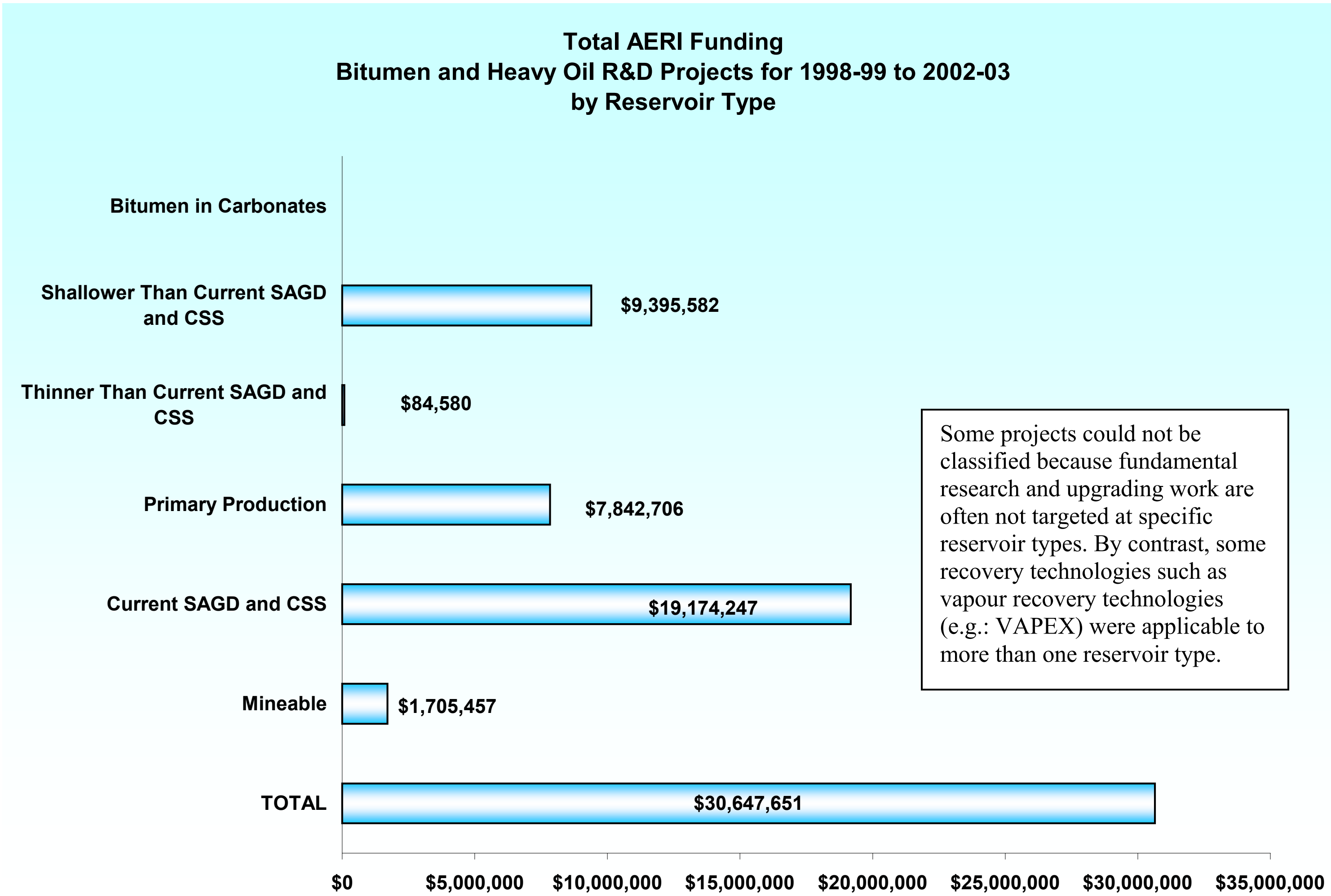
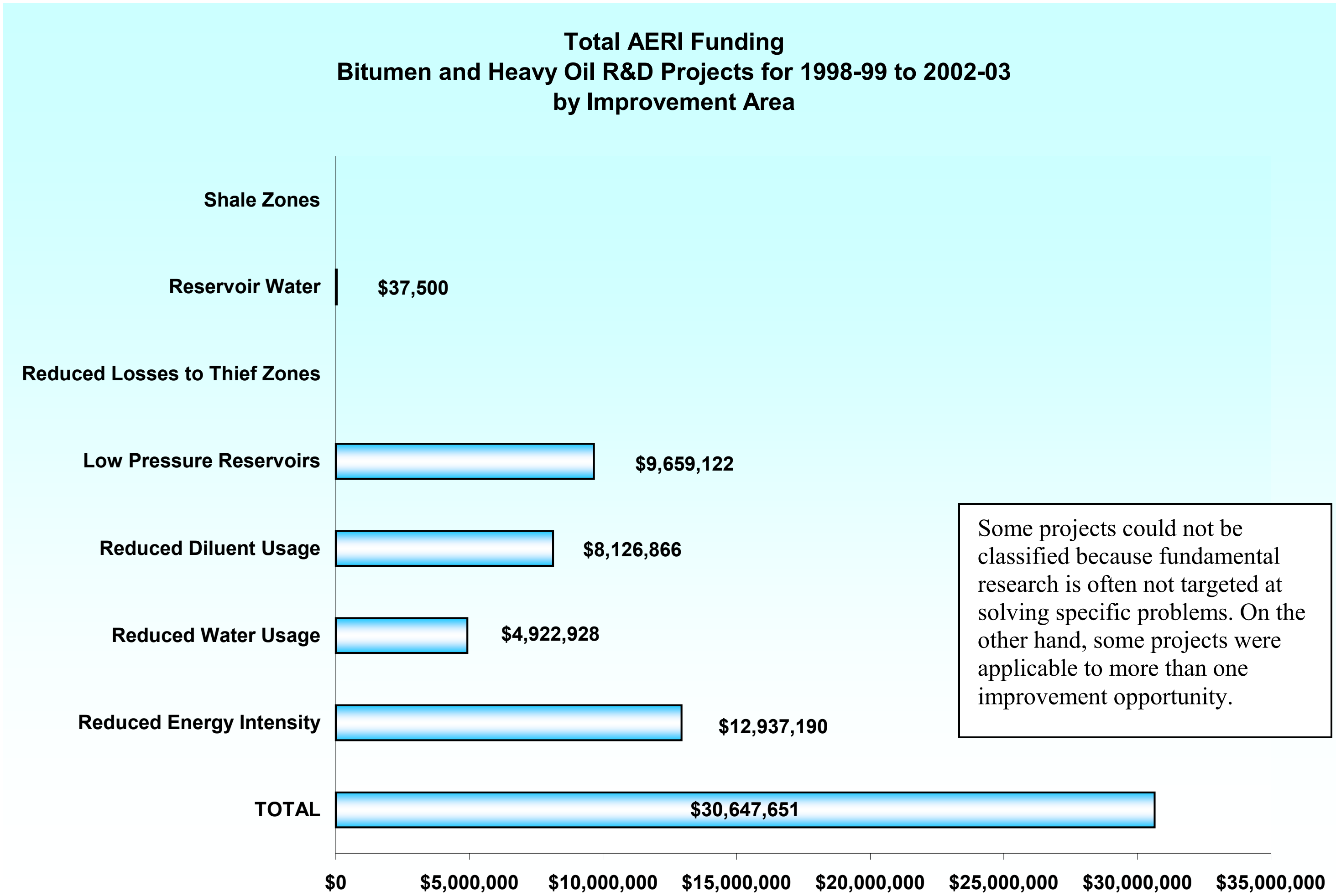


Figure 22 – Total AERI Bitumen and Heavy Oil Research by Major Reservoir Type



Some projects could not be classified because fundamental research and upgrading work are often not targeted at specific reservoir types. By contrast, some recovery technologies such as vapour recovery technologies (e.g.: VAPEX) were applicable to more than one reservoir type.

Figure 23 – Total AERI Bitumen and Heavy Oil Research by Improvement Opportunity



Natural Resources Canada

Natural Resource Canada is a federal government department focused on the sustainable use of natural resources including energy, minerals and metals, forest and earth sciences. As part of its mandate, NRCan conducts research on energy issues. NRCan's CANMET Energy Technology Centre (CETC) for petroleum research is located in Devon, Alberta and is focused on hydrocarbon supply technologies and related environmental technologies with an emphasis on oil sands and heavy oil. CETC Devon is composed of two science and technology groups:

- The National Center for Upgrading Technology (NCUT) is a Canada and Alberta partnership for research into bitumen and heavy oil upgrading. NCUT provides research and technical services to industry and governments. Upgrading is the value added step required to convert bitumen from a black tar substance into the synthetic crude oil required by world markets.
- The Advanced Separation Technologies (AST) group conducts fundamental and applied research to develop and implement multi-phase separation technologies for the petroleum and environmental industries. It works in partnership with industry to solve separation problems. In particular, AST was a co-founder and is an active member of the Tailings Fundamentals Consortium, a program to develop mitigating solutions to tailings disposal issues. It also operates the bitumen froth treatment facility which is used to develop and evaluate improved bitumen froth treatment technologies leading to efficiencies in energy and diluent use.

NRCan's funding share of NCUT and its funding to the AST group at CETC Devon were aggregated and analyzed on Figures 24 to 27. Total NRCan funding over the past five years for research into bitumen and oil sands was $46.7 million. Over 60% of this amount, or $31.6 million, was allocated to applied research. The balance was spent on fundamental research. Upgrading took the lion's share of NRCan funding or $26.1 million. It is important to note that NRCan spent $9.3 million over five years on environmental issues which represents over 70% of the total amount of public funds directed at environmental issues. Whether it is upgrading or advanced separation technologies, the research work performed in Devon is applicable to bitumen and heavy oil from all types of reservoir. However, this research was not allocated to any specific type of reservoir because it is directed at challenges and opportunities that arise after the oil has been extracted from a reservoir.

Figure 24 – Total NRCan Bitumen and Heavy Oil Research by Research Stage

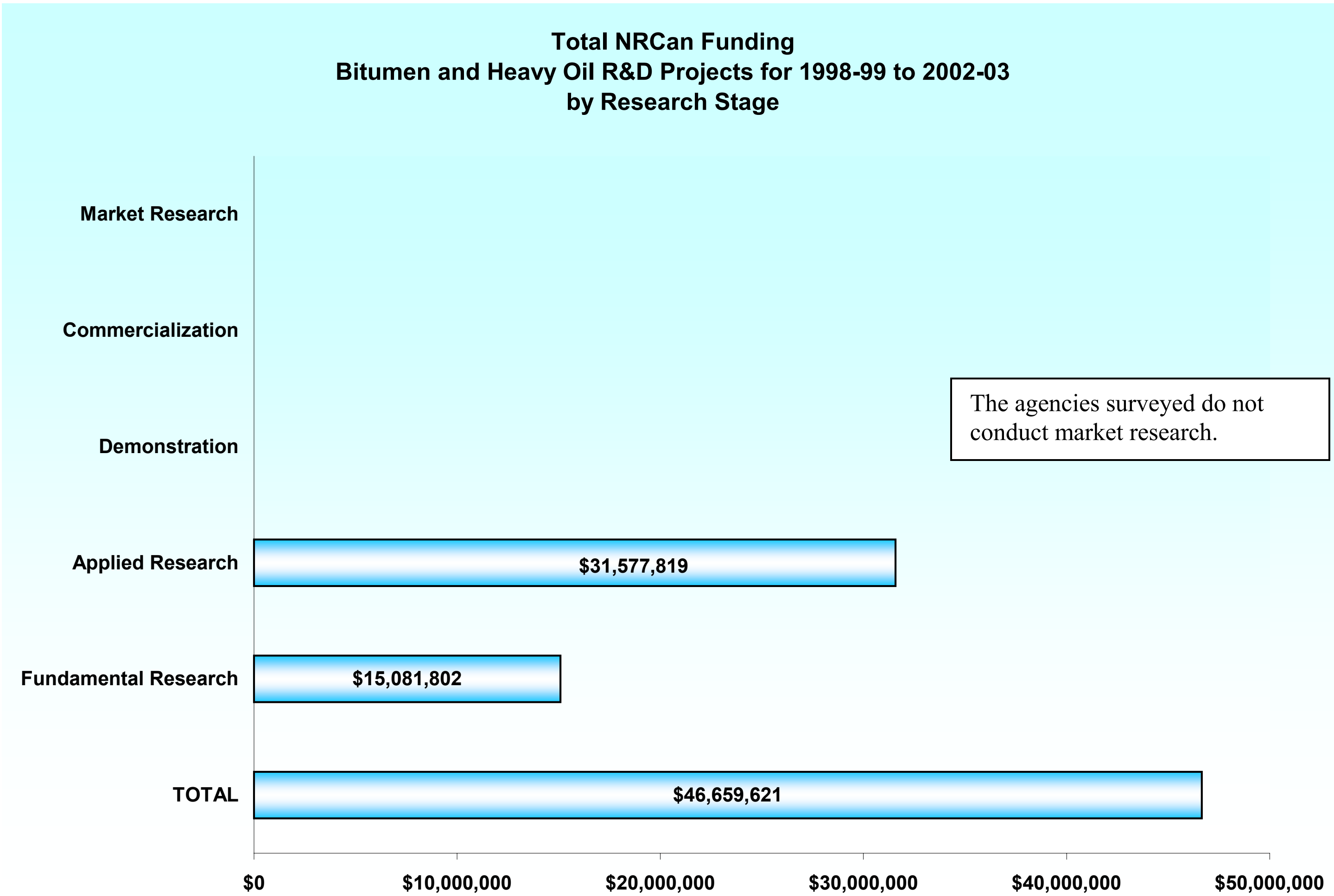


Figure 25 – Total NRCan Bitumen and Heavy Oil Research by Life Cycle Stage

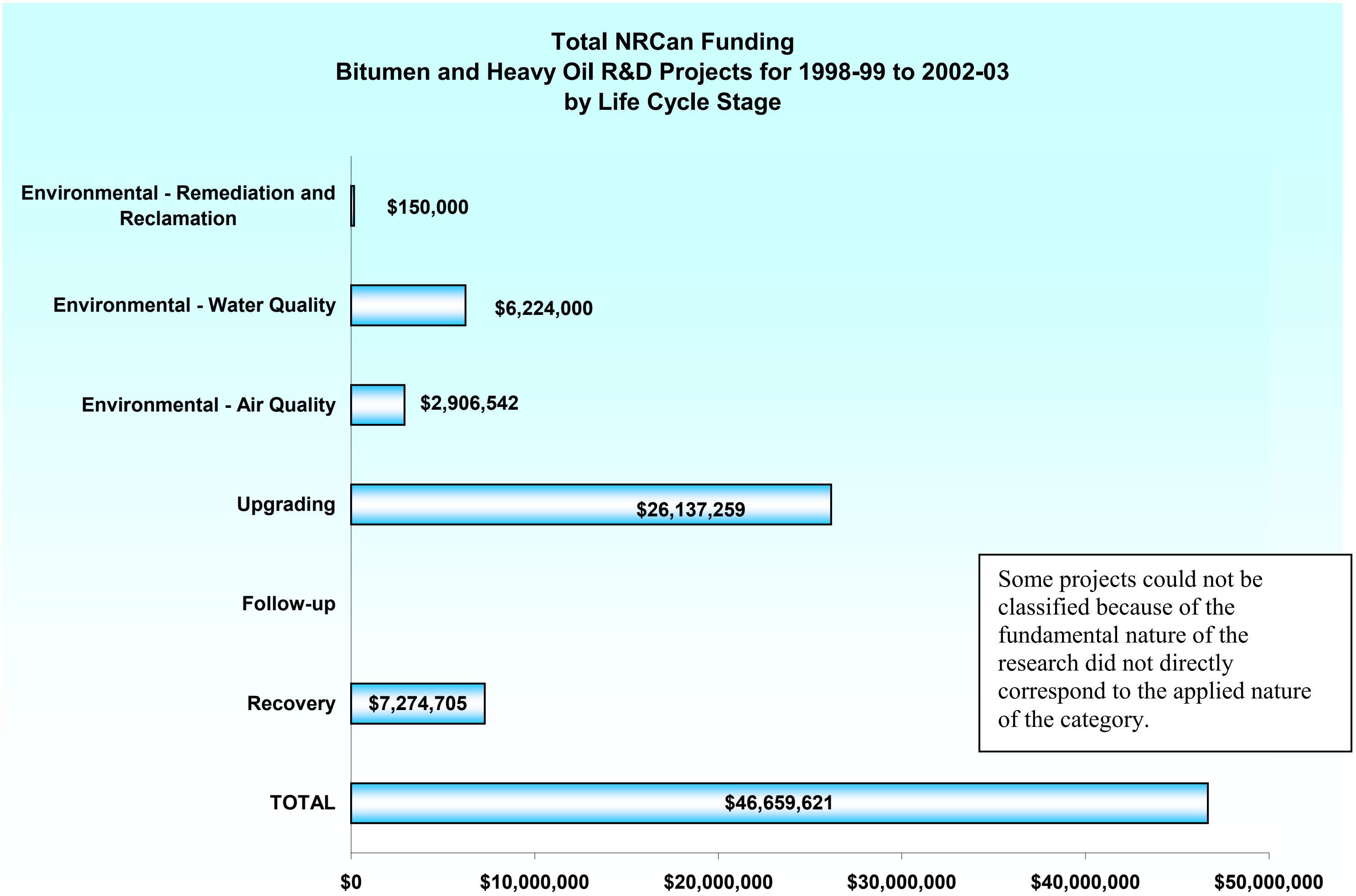


Figure 26 – Total NRCan Bitumen and Heavy Oil Research by Major Reservoir Type

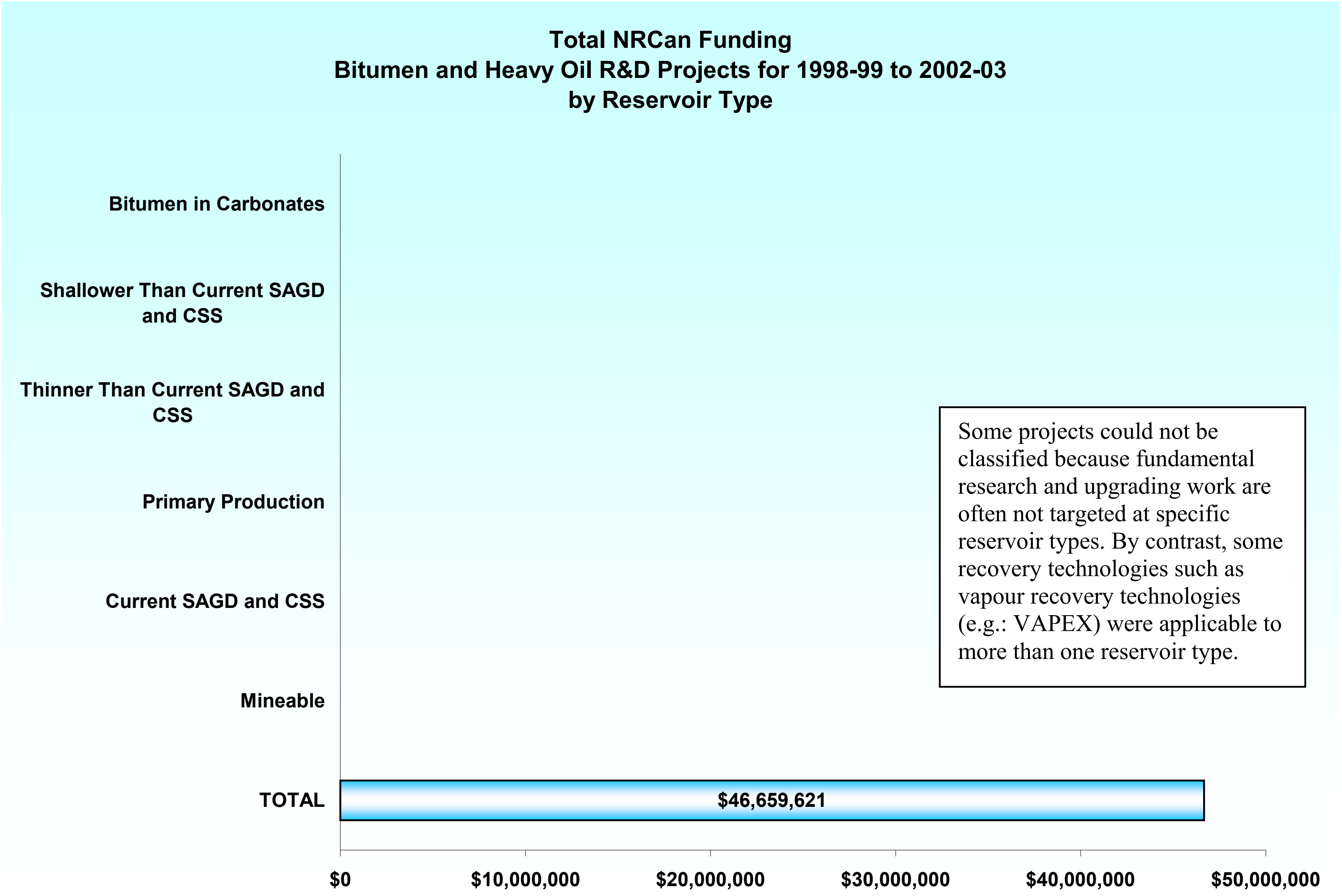
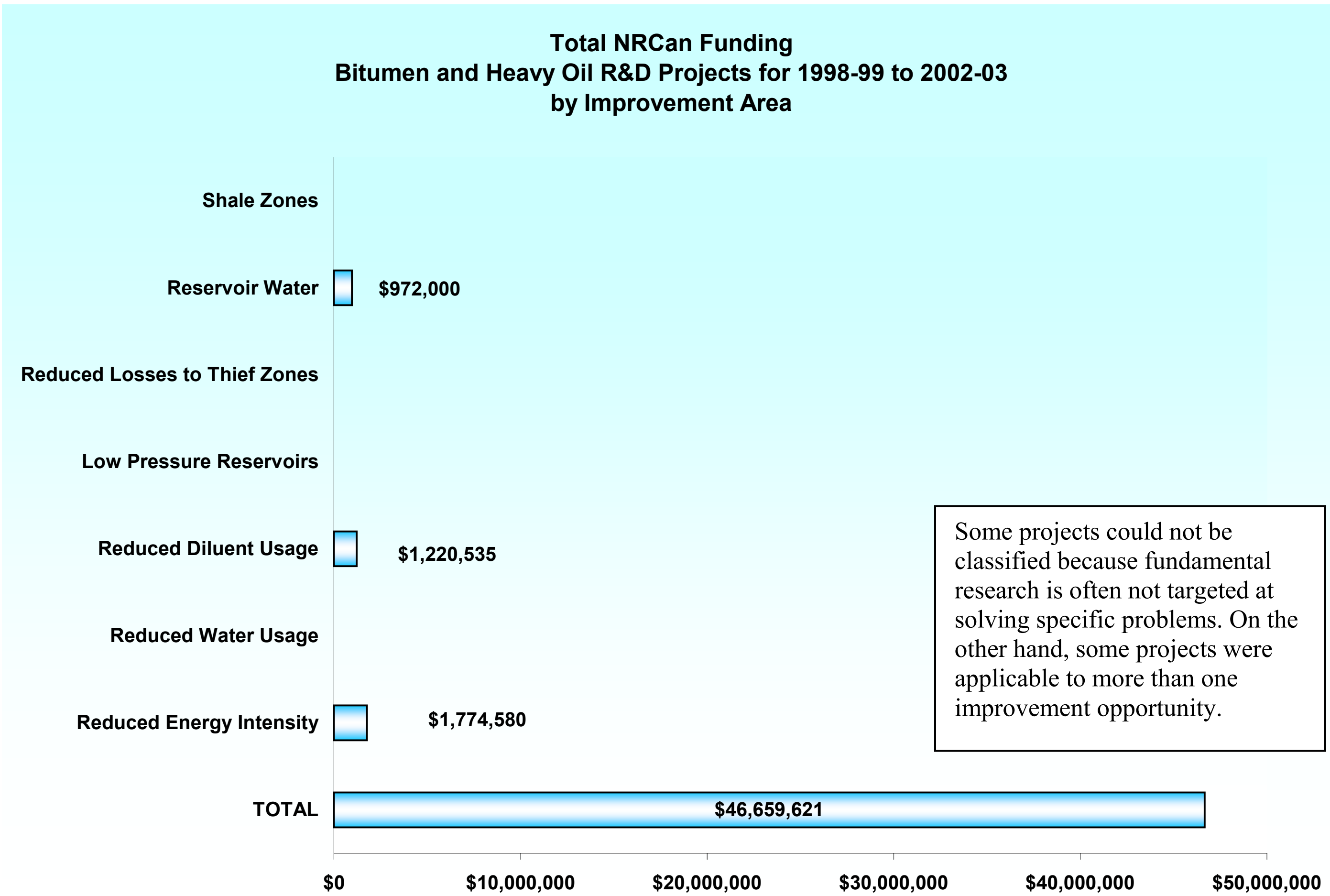


Figure 27 – Total NRCan Bitumen and Heavy Oil Research by Improvement Opportunity



Canada Foundation for Innovation

The Canada Foundation for Innovation (CFI) was created in 1997 by the federal government to fund research infrastructure. The mandate of the CFI is to strengthen the capability of Canadian universities, colleges, research hospitals and other nonprofit institutions to carry out research and technology development for the benefit of Canada. The CFI has a budget of $3.65 billion of which $2.6 billion has been committed as of March 2004. It will fund up to 40 % of a projects infrastructure costs. The grants are awarded using a merit based assessment process that involves evaluation teams composed of researchers, research administrators and research users from Canada and abroad who review proposals and make funding recommendations. The selection process is based on the following criteria:

- quality of the research and need for infrastructure
- contribution to strengthening the capacity for innovation
- potential benefits of the research to Canada

Canada Research Chairs

In 2000, the government of Canada budgeted $900 million for the Canada Research Chairs program to establish 2000 research professorships in universities across the country. The expectation is that chairholders not only conduct research but also teach and supervise students, and coordinate the work of other researchers. The goals of the Canada Research Chairs program are to strengthen research excellence in Canada, to improve the training of highly qualified personnel, and to improve the capacity for creating and applying new knowledge.

University Research and Strategic Investments

The University Research and Strategic Investments (URSI) branch of Alberta Innovation and Science coordinates the funding processes for the Alberta Science and Research Investments Program (ASRIP) and other granting programs of the Alberta Science and Research Authority (ASRA). ASRIP is a competitive funding program designed to support targeted science and research initiatives of strategic importance to Alberta. The overall objective is the promotion of strategic quality innovation. The program also serves as a mechanism to leverage support from other funding sources such as the Canada Foundation for Innovation and the private-sector in order to maximize research investment in Alberta. The program has two funding streams:

- Research infrastructure:
    - Increasing research excellence and competitiveness in Alberta
    - Assisting Alberta universities in attracting and retaining high quality faculty and graduate students

- Encouraging the development of collaborative centers of excellence

- Enabling research application and technology transfer:
    - Enhancing capacity to capitalize on the benefits of research
    - Technology commercialization networking
    - Strengthening partnerships between research organization and industry.

Analysis of CFI, CRC and URSI/ASRIP Funding

Contributions to oil sands research from the Canada Foundation for Innovation ($7.9 million), the Canada Research Chairs program ($0.7 million) and programs administered by Alberta University Research and Strategic Investments ($6.4 million) were aggregated for the purpose of analysis because they are all directed at supporting fundamental university research. Results from the analysis are shown on Figures 28 to 31. Total funding from these three programs for bitumen heavy oil research over the past five years was $15.0 million. Of this amount, $12.1 million was directed at recovery. Most university infrastructure and research chair projects are broadly scoped and are of fundamental nature. As a result, few were targeted at extracting oil from specific reservoir types or solving specific industry problems. Therefore, few infrastructure projects and research chairs were allocated to the reservoir types and improvement opportunities considered by this study.

Figure 28 – Total CFI, CRC and URSI/ASRIP Bitumen and Heavy Oil Research by Research Stage

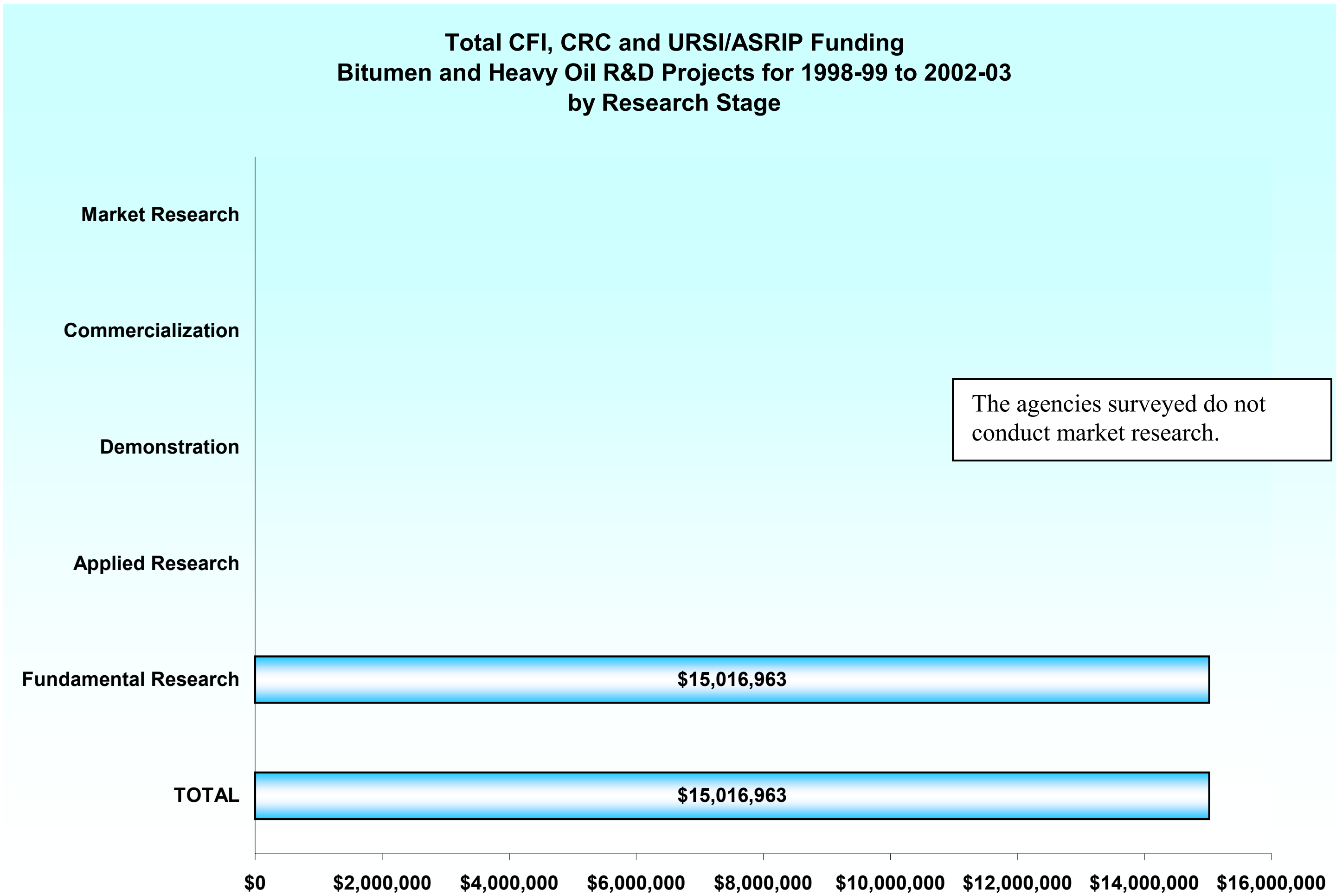
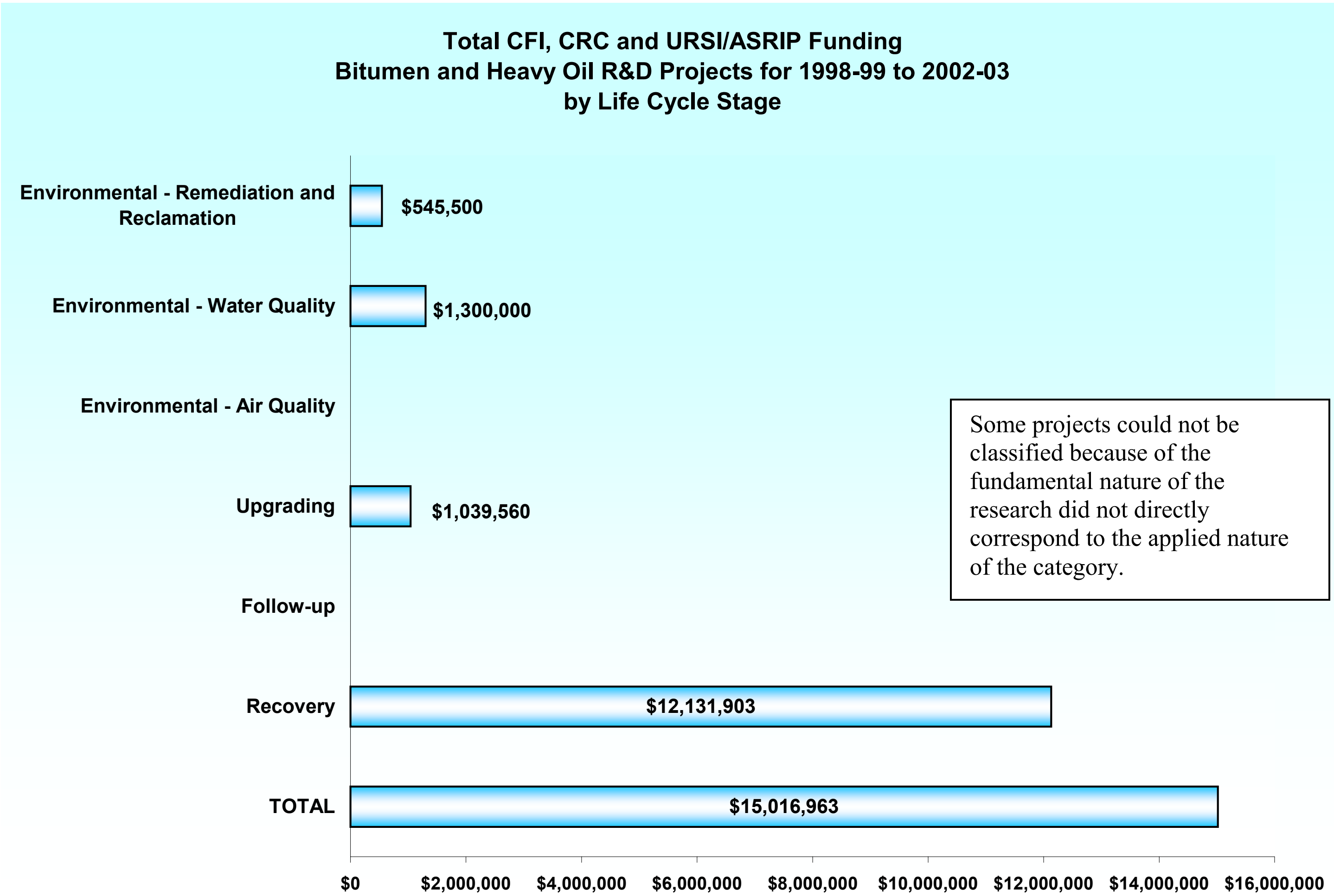


Figure 29 – Total CFI, CRC and URSI/ASRIP Bitumen and Heavy Oil Research by Life Cycle Stage



Some projects could not be classified because of the fundamental nature of the research did not directly correspond to the applied nature of the category.

Figure 30 – Total CFI, CRC and URSI/ASRIP Bitumen and Heavy Oil Research by Major Reservoir Type

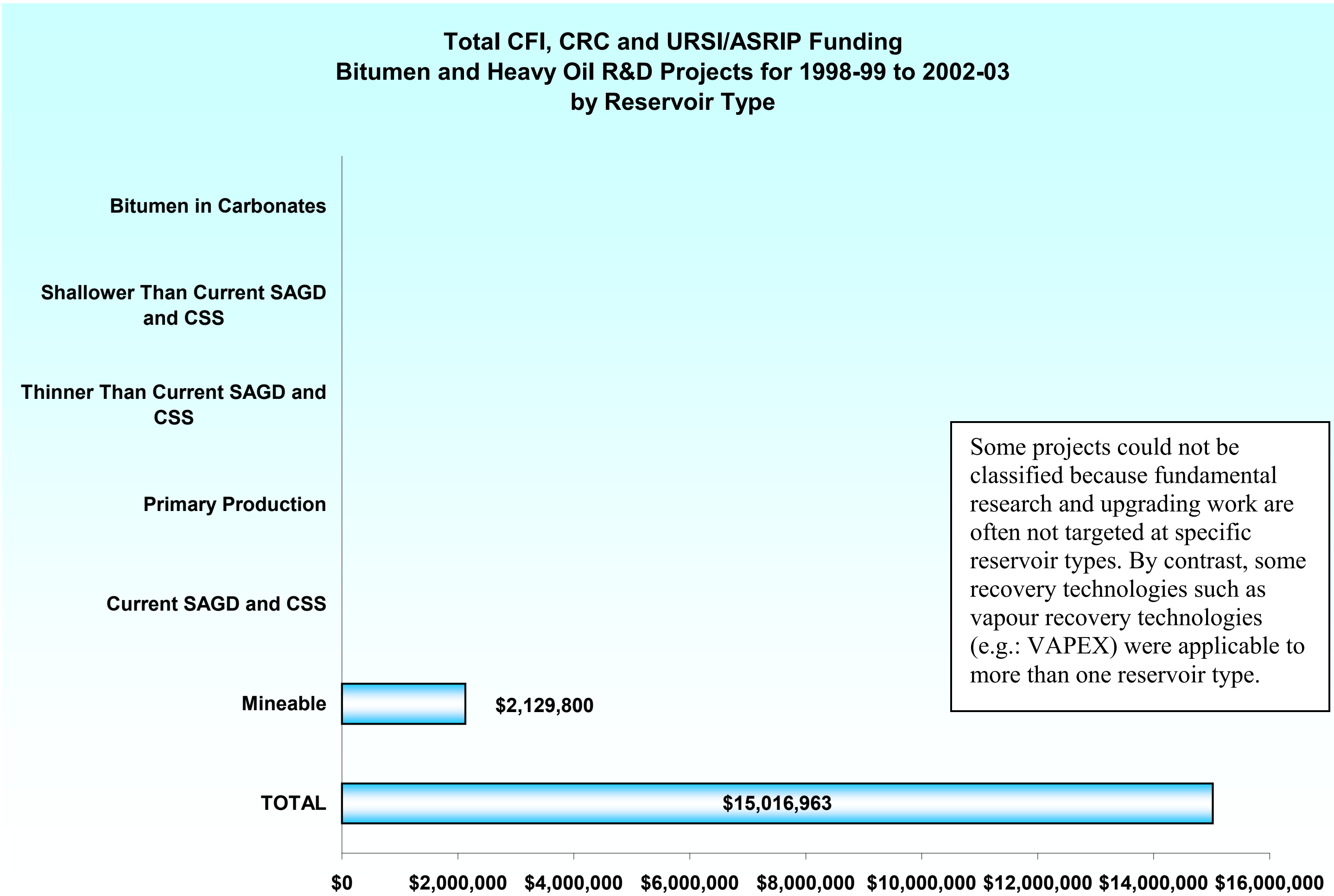
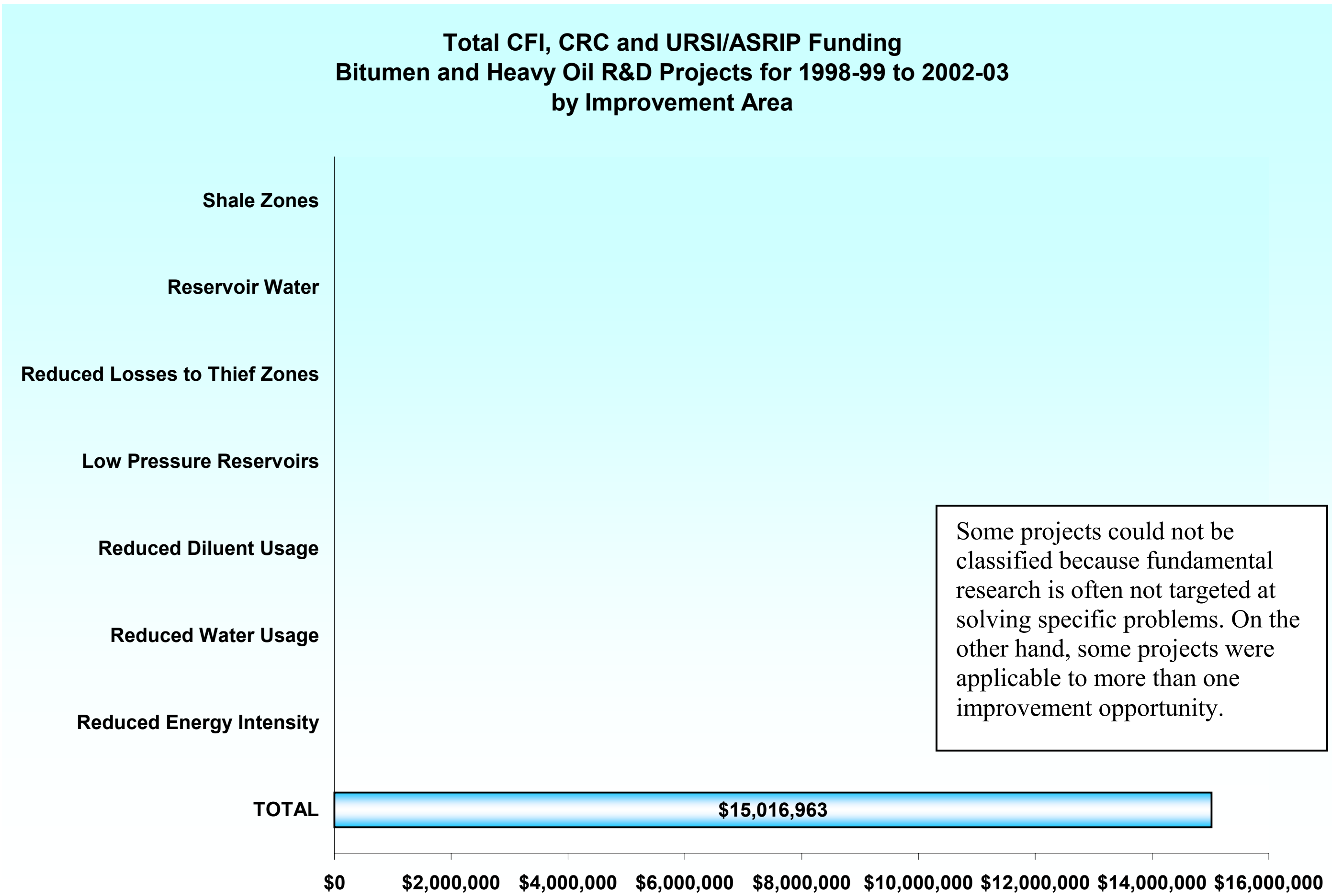


Figure 31 – Total CFI, CRC and URSI/ASRIP Bitumen and Heavy Oil Research by Improvement Opportunity



National Science and Engineering Research Council

The National Science and Engineering Research Council of Canada (NSERC) is a federal granting council that makes investments in people, discovery and innovation for the benefit of Canada. NSERC funding supports more than 17,700 university students and postdoctoral fellows pursuing advanced studies and provides grants that support research conducted by more than 9,600 university professors every year. NSERC funding is leveraged by contributions from more than 500 Canadian companies. In 2003-2004, NSERC's funding budget will be a total of $760 million for university based research and training in all the natural sciences and engineering.

NSERC funds a very large number of research projects at Canadian universities every year. The NSERC database was searched and over 180 projects related to bitumen and heavy oil were identified, reviewed and included in this inventory. The total amount of NSERC funding for these projects was $8.1 million over five years. The analysis of NSERC projects is shown on Figures 32 to 35. All were fundamental research projects and approximately half, or $4.1 million were directed at recovery.

Petroleum Technology Alliance of Canada

The Petroleum Technology Alliance of Canada (PTAC) facilitates innovation, technology transfer and research & development in the upstream oil and gas industry. Its objective is to improve the performance of the industry in areas such as environmental, safety and financial. PTAC is a not for profit association with 174 members classified as follows:

- 24 producers representing approximately 70% of Canadian conventional oil and gas
- 118 service and supply organizations
- 14 research providers and learning institutions
- 14 individuals and inventors
- 4 government members

PTAC does not fund or conduct research. The association acts as a bridge and matchmaker between clients, funding organizations and research providers. Since 1997, PTAC has facilitated 194 research projects with an aggregate value of $110 million. A large number of these projects originated from the COURSE program of the Alberta Energy Research Institute. Also included are six pilot demonstration projects conducted by industry with an approximate value of $76 million. In the heavy oil area, PTAC facilitated 32 projects valued at approximately $14 million. With respect to oil sands development, PTAC facilitated 20 projects valued at approximately $5 million.

PTAC is neither a funding organization nor a research provider. Its role is one of facilitation between the funding agencies and the research providers covered in this report. Consequently, no projects were assigned to PTAC.

Figure 32 – NSERC Bitumen and Heavy Oil Research by Research Stage

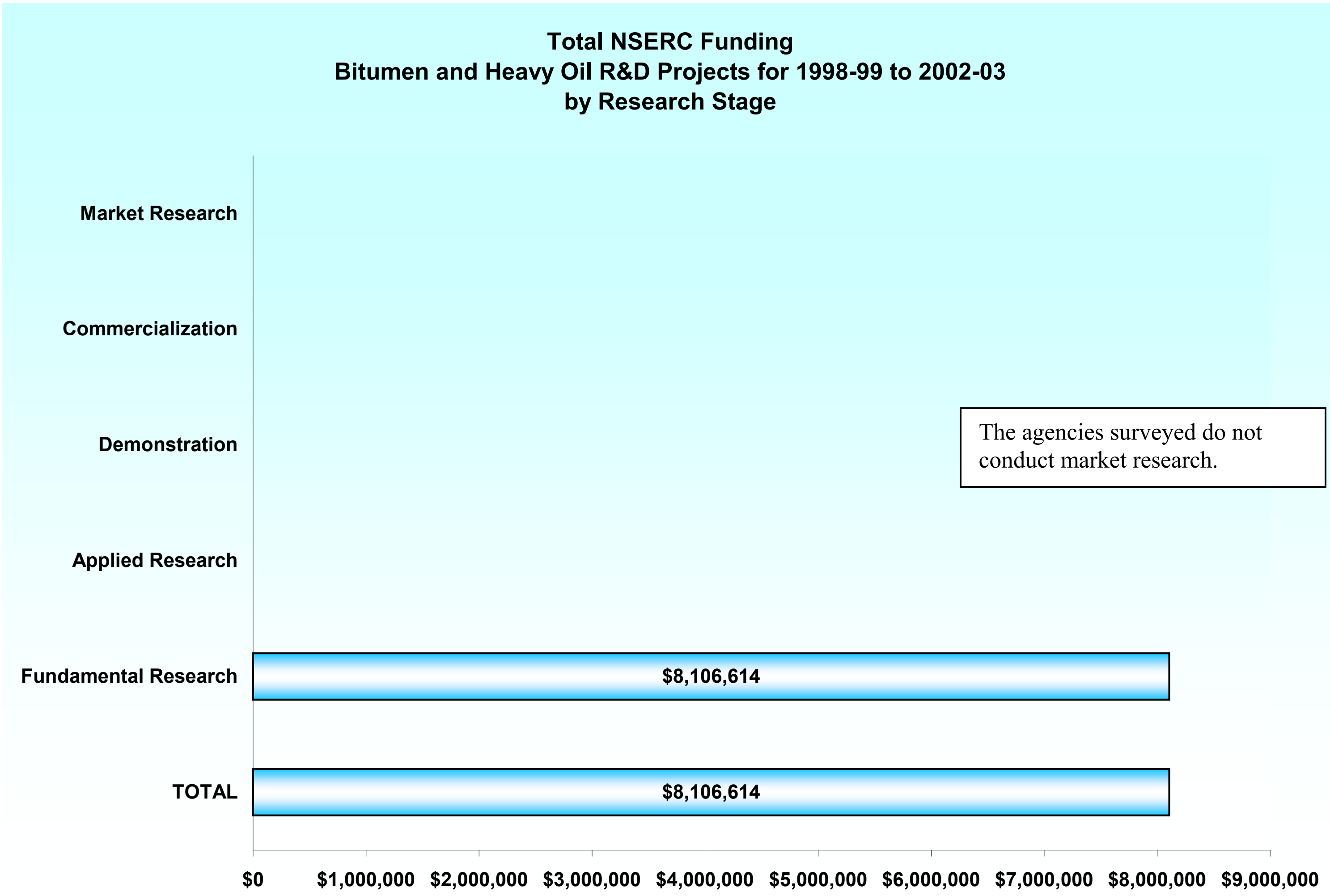


Figure 33 – NSERC Bitumen and Heavy Oil Research by Life Cycle Stage

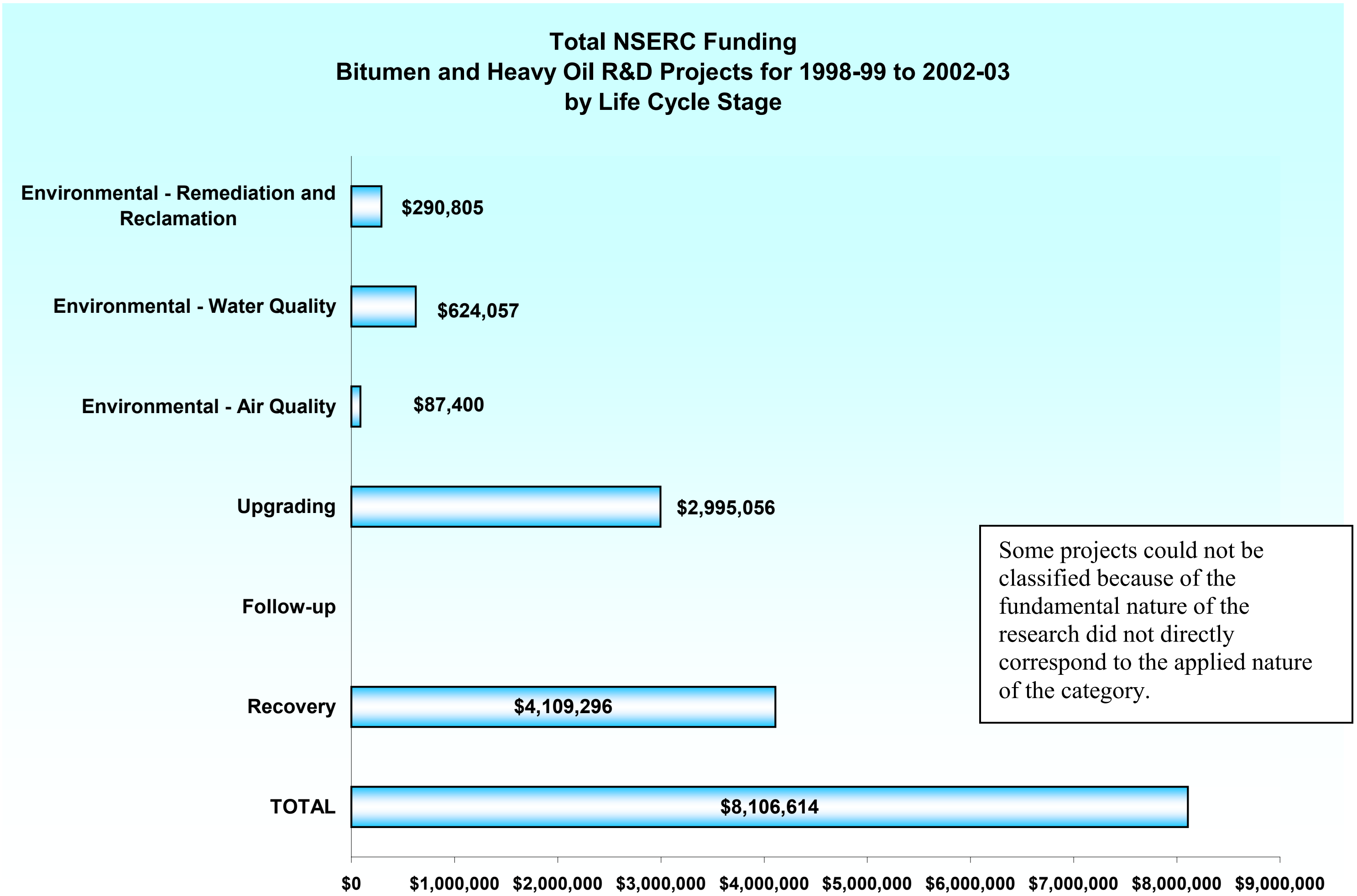


Figure 34 – NSERC Bitumen and Heavy Oil Research by Major Reservoir Type

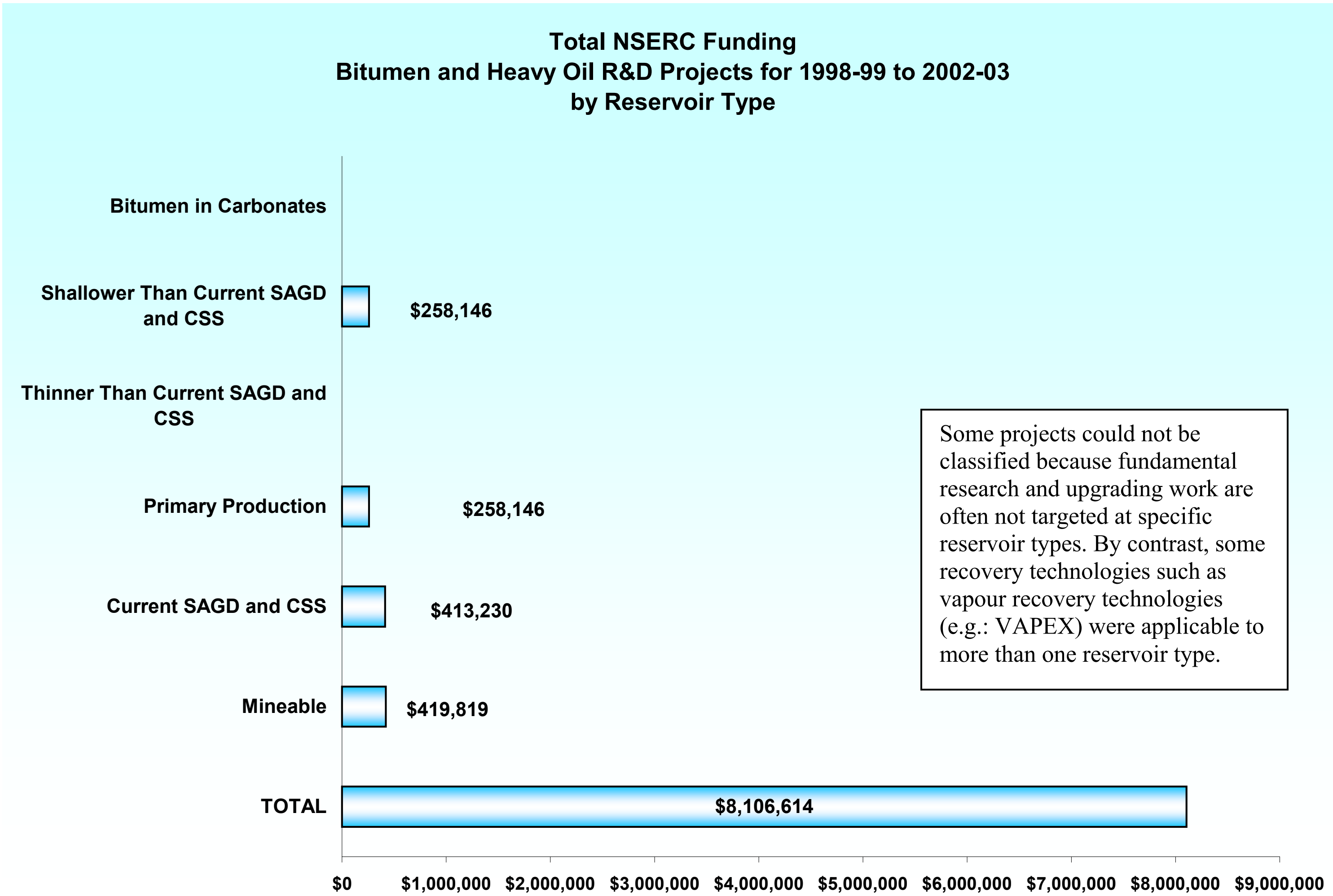
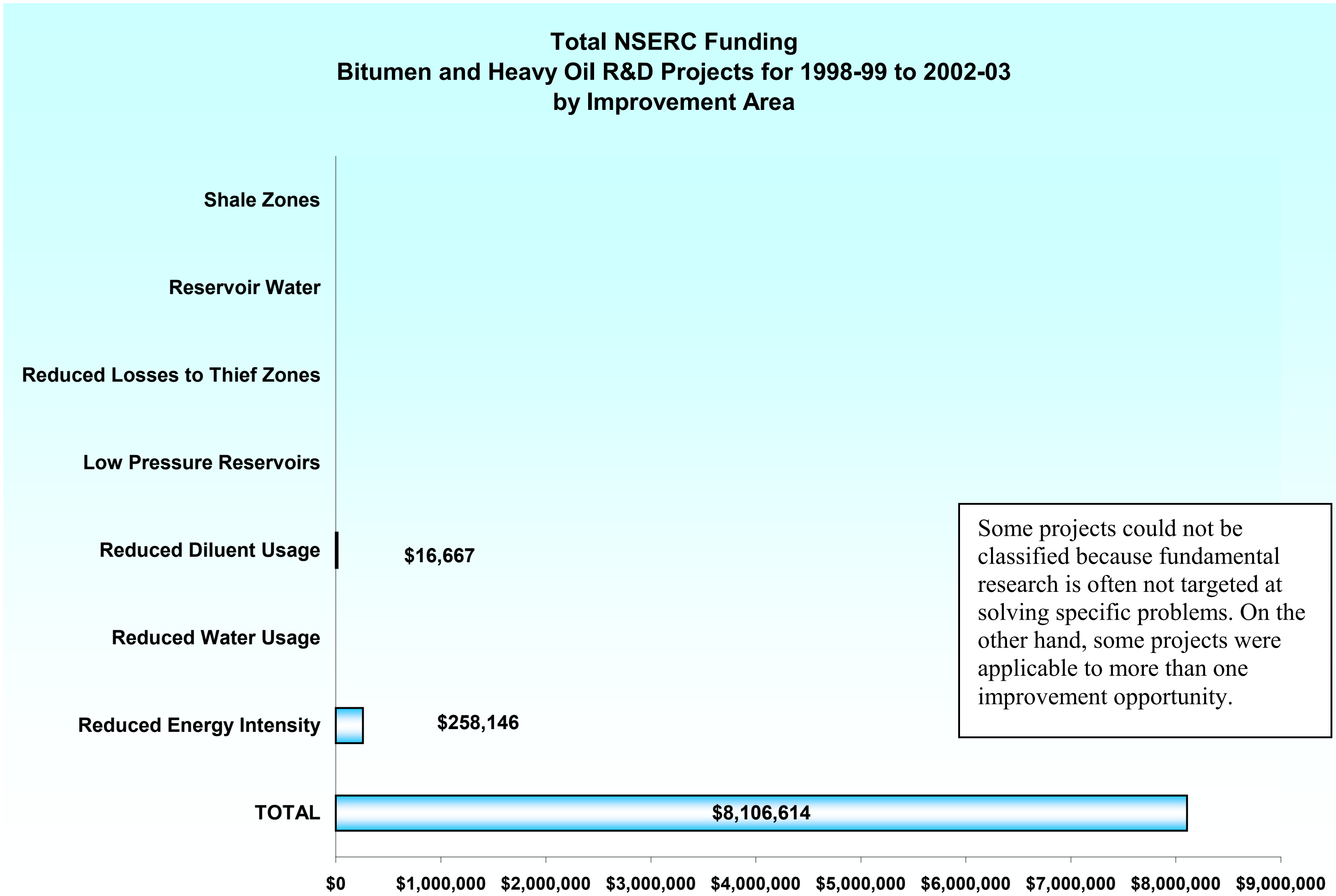


Figure 35 – NSERC Bitumen and Heavy Oil Research by Improvement Opportunity



Review of Research Providers

The University of Alberta

Opened in 1908, the University of Alberta is recognized as one of Canada's foremost research intensive universities. External funding in 2002-2003 was in excess of $300 million. The University offers over 200 undergraduate programs and 170 graduate programs to nearly 34,000 students.

The University of Alberta has a wide with the energy, petroleum and oil sands sectors. The following facilities are involved in oil sands research

- Surface Mining Research Laboratory
- Colloids and Complex Fluids
- Competitive wear/surface research laboratory
- Thermal and solvent enhanced oil recovery laboratory
- Alberta Centre for Surface Engineering and Science (ACSES)
- Tailings Research Facility
- Geotechnical and Geo-environmental Cold Regions Research Facility

The following research chairs are active in oil sands research:

- Canada Research Chair in Oil Sands Engineering: enhanced methods of bitumen extraction and faster reclamation of waste by-products.
- Canada Research Chair in Colloids and Complex Fluids: how fluids will react in oil sands recovery, environmental spill cleanup, sewage treatment and other situations involving complex fluids.
- Industrial Research NSERC Chair on Advanced Upgrading of Bitumen
- NSERC Chair in Petroleum Thermodynamics.

The University of Alberta conducted $12.7 million of fundamental bitumen and heavy oil research during the past five years. Figures 36 to 39 present the analysis. Over half of the projects or $7.4 million were targeted at recovery aspects. Upgrading projects were also important at $2.2 million as a result of the presence of the Industrial Research Chair on Advanced Upgrading of Bitumen and the associated Alberta Center for Surface Engineering and Science. Environmental projects received $2.5 million due to the presence of the Tailings Research Facility and the related Geotechnical and Geo-environmental Cold Regions Research Facility. Projects directed at mineable reservoirs attracted $3.7 million because of the presence at the University of Alberta of the Surface Mining Research Laboratory and the Competitive Wear Surface Research Laboratory.

Figure 36 – University of Alberta Bitumen and Heavy Oil Research by Research Stage

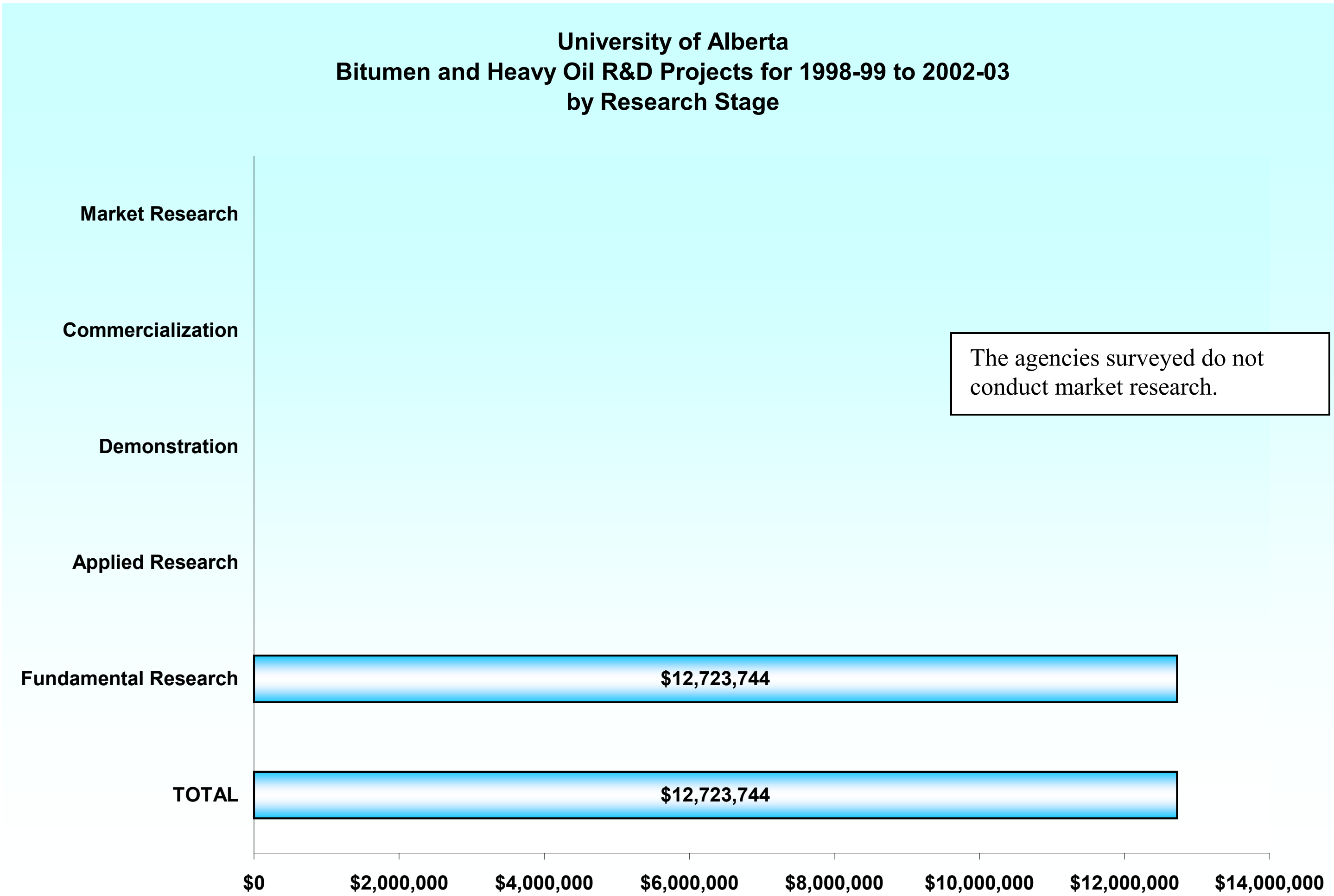


Figure 37 – University of Alberta Bitumen and Heavy Oil Research by Life Cycle Stage

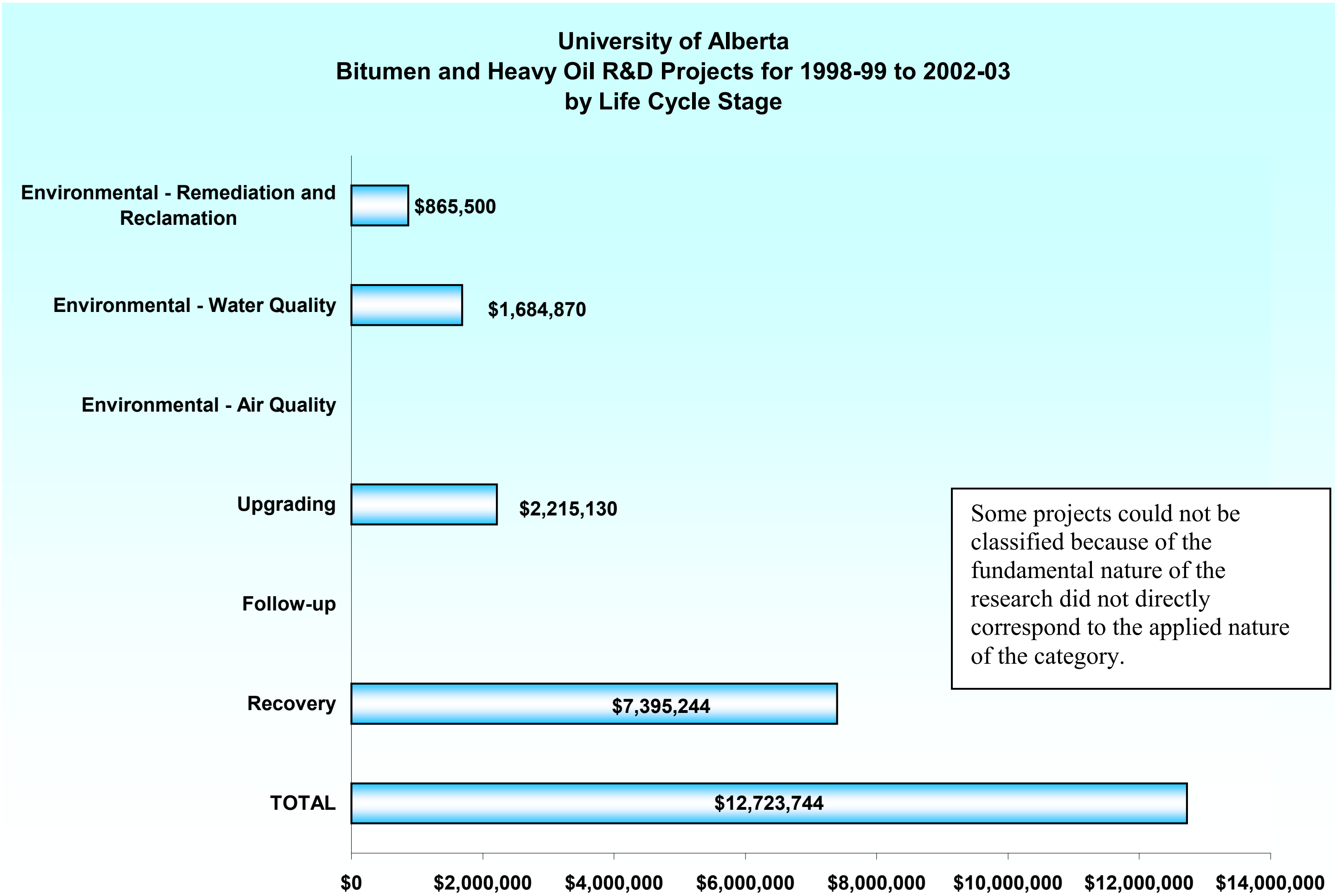


Figure 38 – University of Alberta Bitumen and Heavy Oil Research by Major Reservoir Type

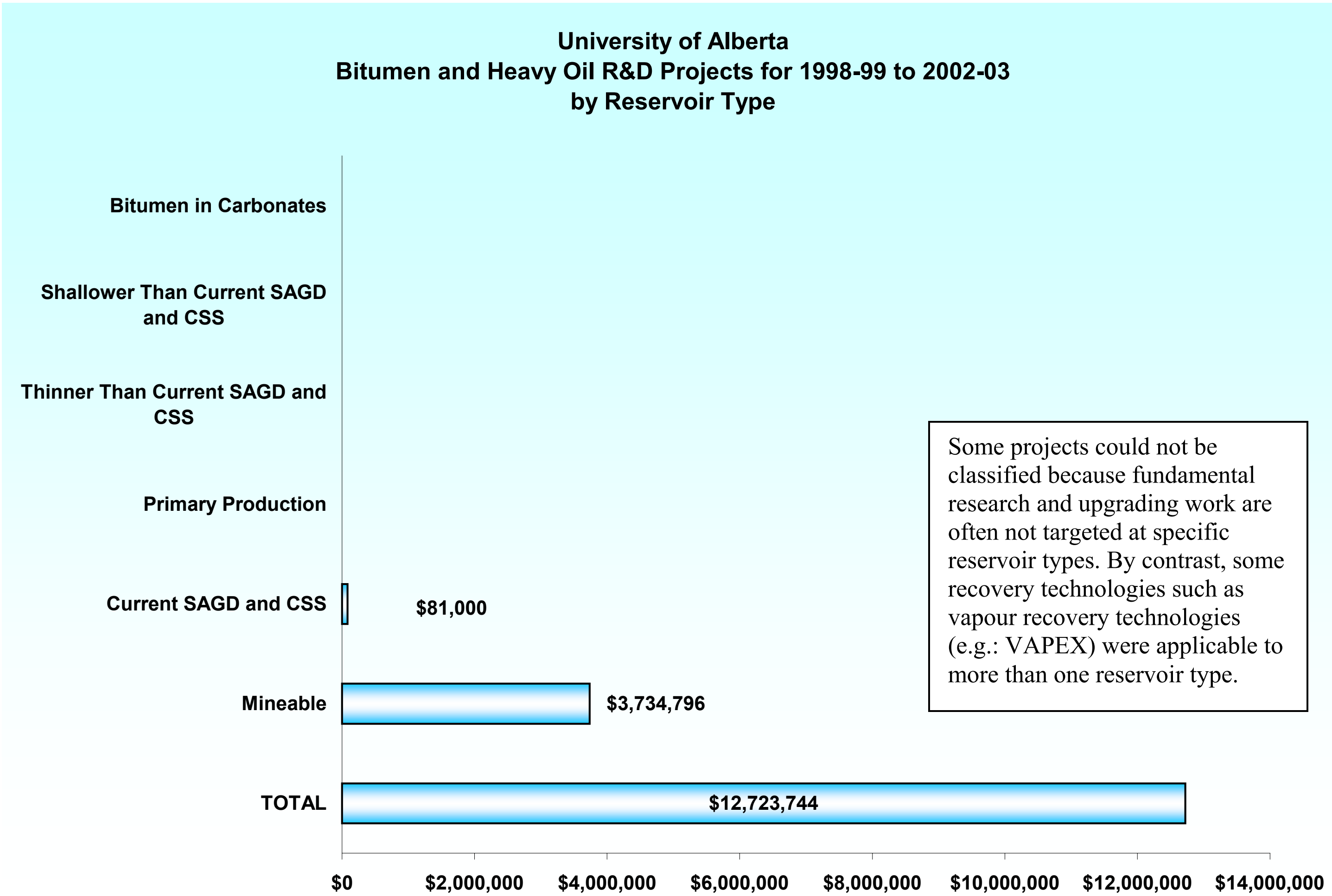
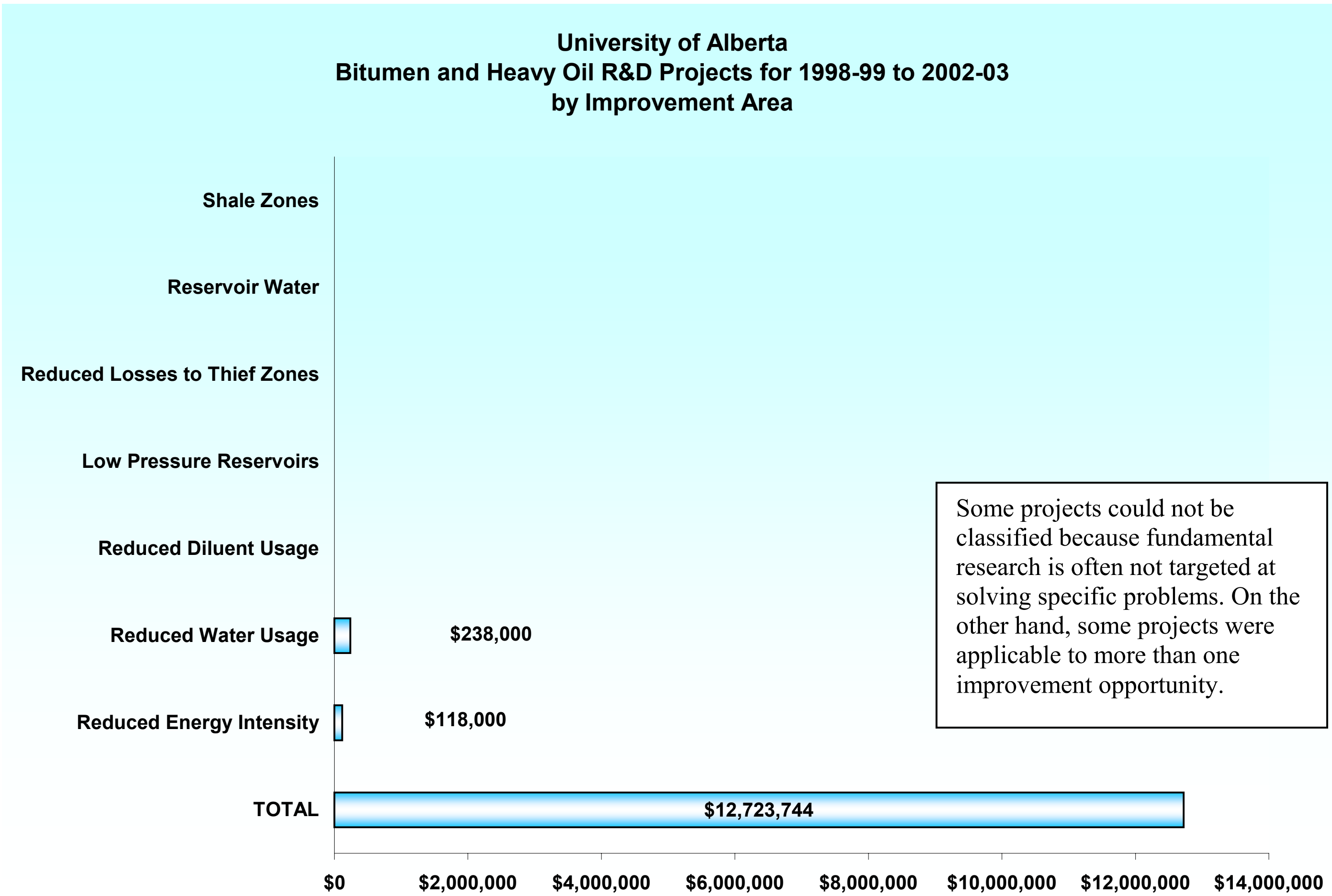


Figure 39 – University of Alberta Bitumen and Heavy Oil Research by Improvement Opportunity



The University of Calgary

The University of Calgary became an autonomous institution in 1966. In 2002, approximately 28,000 students attended the University of Calgary. External research funding in 2001-2002 was in excess of $177 million. The recently developed academic plan identifies four strategic priorities:

- Leading innovation in energy and the environment
- Understanding human behavior institutions and cultures
- Creating technologies and managing information for the knowledge society
- Advancing health and wellness.

The University of Calgary has an excellent track record of collaborating with the petroleum industry. The following facilities are used to conduct oil sands research:

- Energy and Imaging
- Integrated Reservoir Engineering and Advanced Visualization

In addition, the Canada Research Chair in Energy and Imaging manages a research portfolio that includes oil sands projects.

Over the five years covered by this study, the University of Calgary spent $11.4 million on bitumen and heavy oil research. As shown on figures 40 to 43, over 90% of the research conducted at the University of Calgary was dedicated to recovery. However most of the research was of the fundamental nature and could not appropriately be allocated to specific reservoir types or specific industrial improvement opportunity.

Figure 40 – University of Calgary Bitumen and Heavy Oil Research by Research Stage

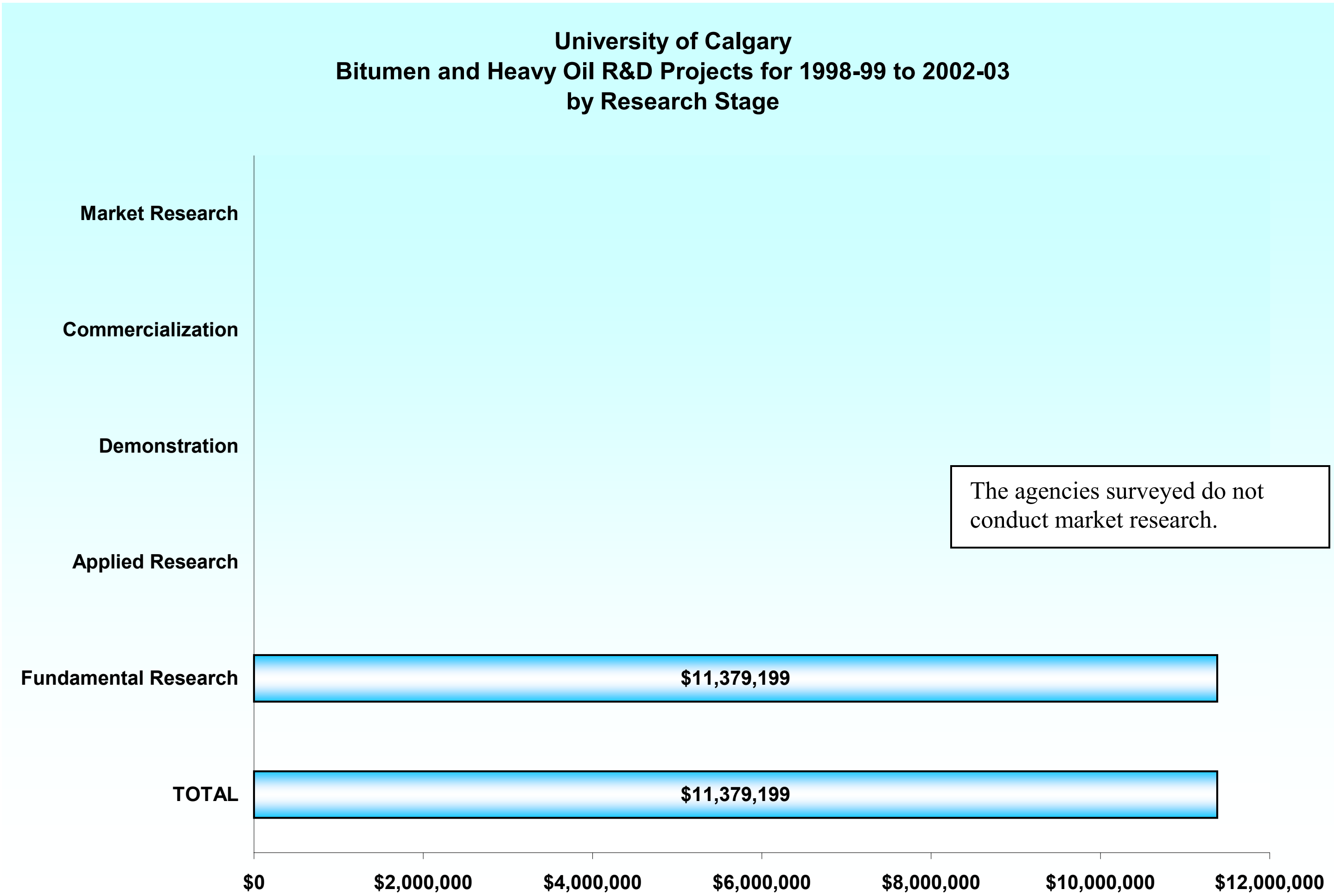


Figure 41 – University of Calgary Bitumen and Heavy Oil Research by Life Cycle Stage

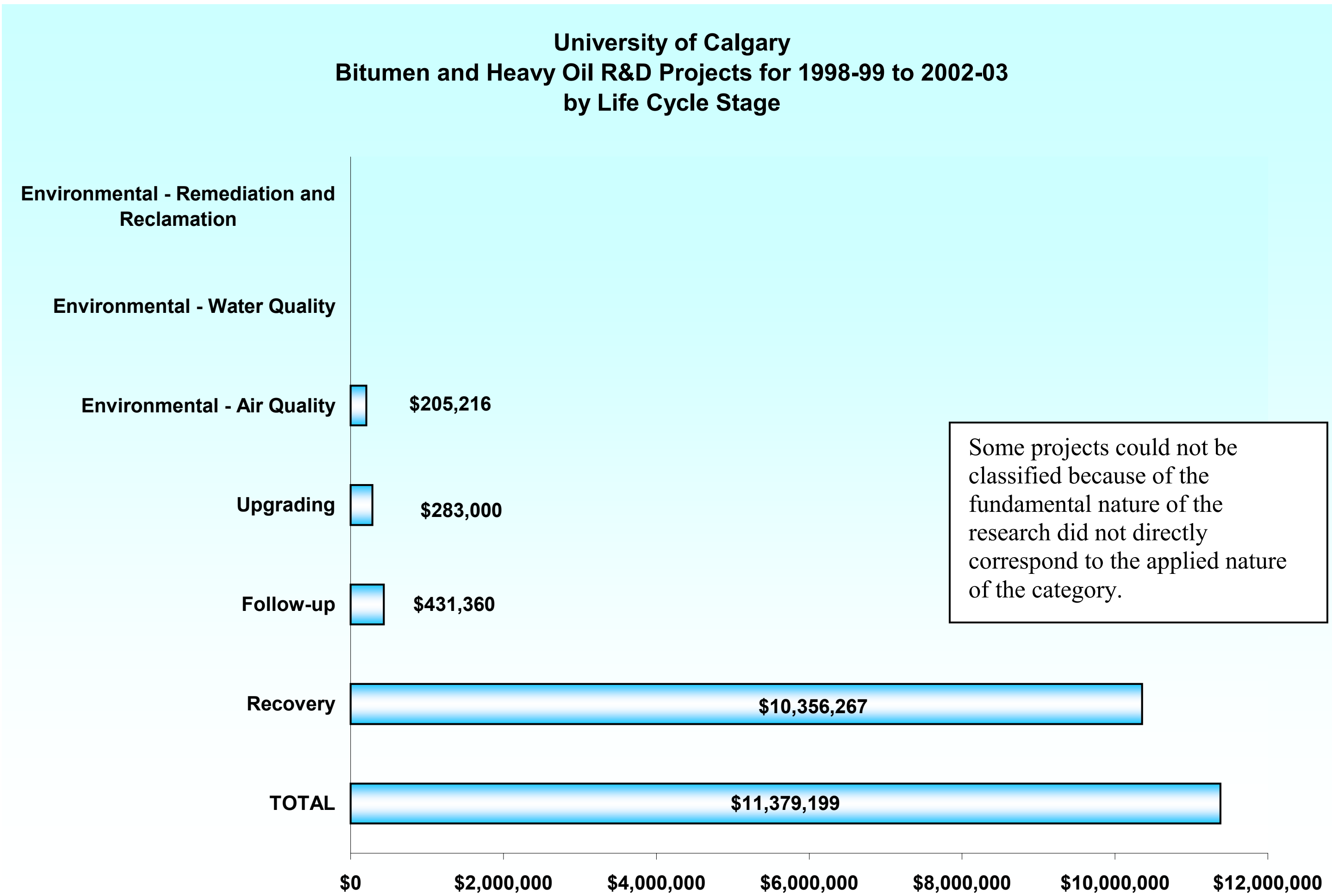


Figure 42 – University of Calgary Bitumen and Heavy Oil Research by Major Reservoir Type

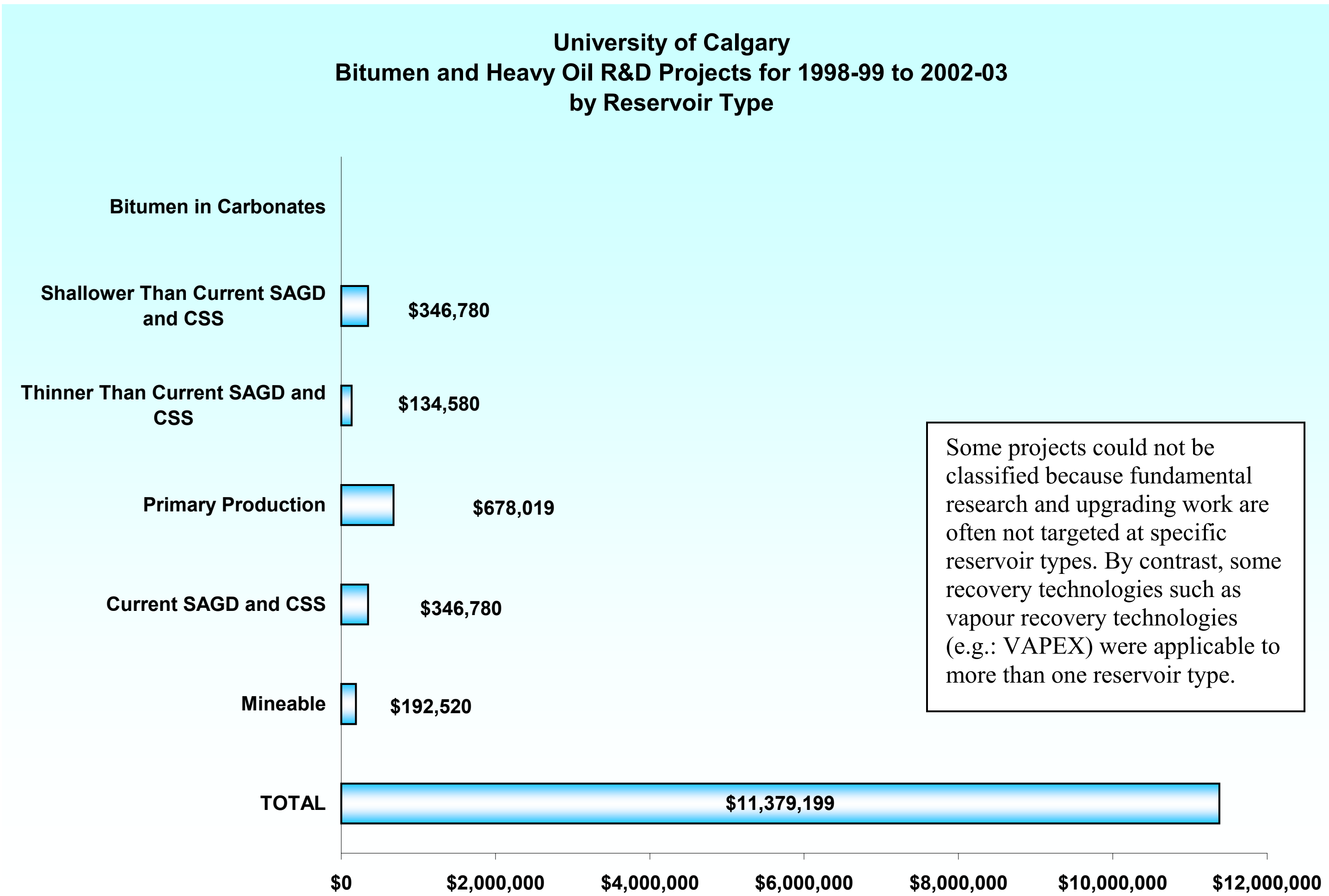
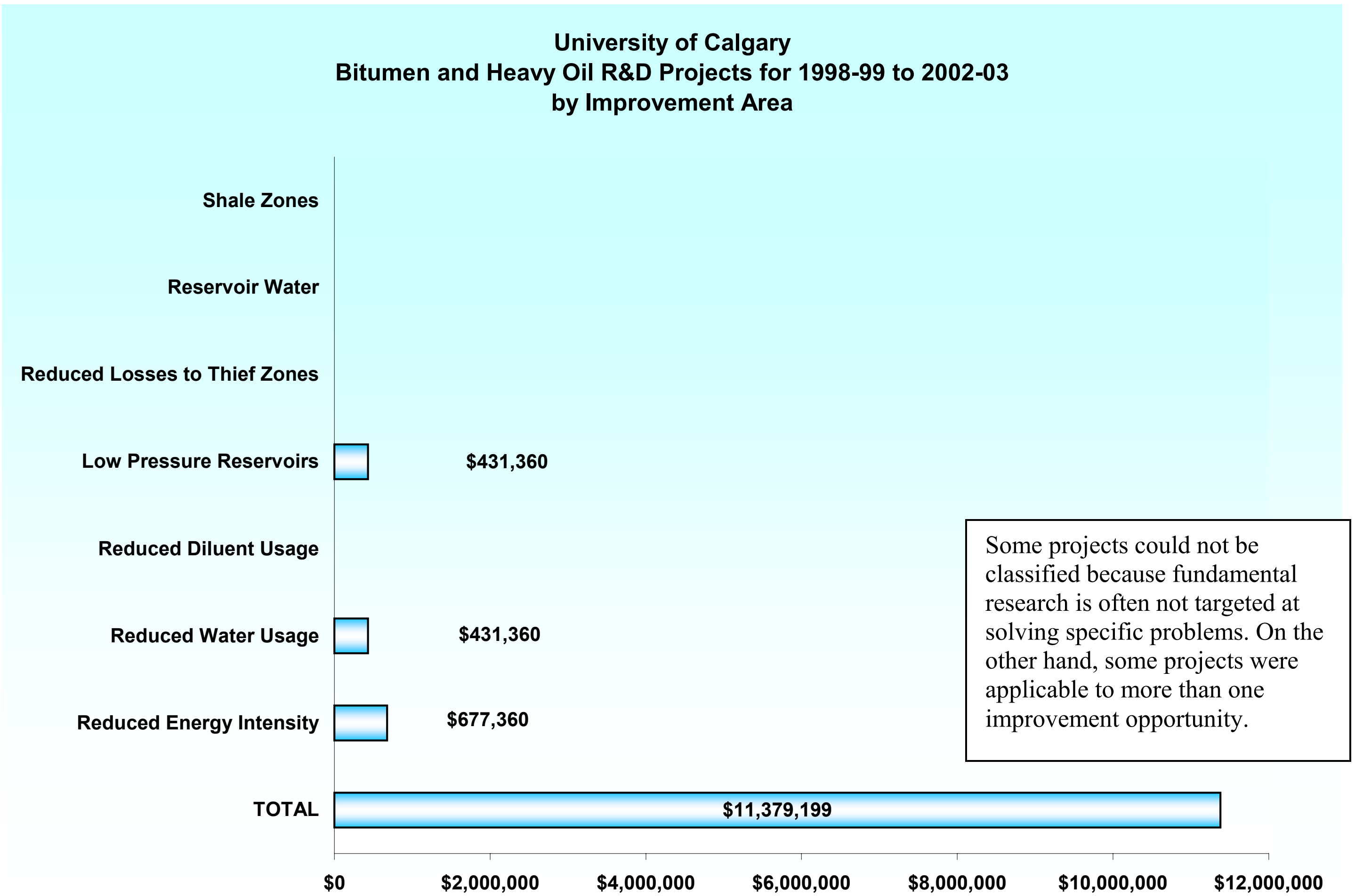


Figure 43 – University of Calgary Bitumen and Heavy Oil Research by Improvement Opportunity



Alberta Research Council and the AERI-ARC Core Industry (AACI) Program

The Alberta Research Council (ARC) was established in 1921 and was the first provincial research organization in Canada. Its initial mandate was to document Alberta's mineral and natural resources for industry. Today, the Alberta Research Council develops and commercializes technologies that provide clients with a competitive advantage. ARC is focused on energy, life-sciences, agriculture, environment, forestry and manufacturing. ARC performs applied research and development on a contract or co-venture basis. The ARC team is drawn from approximately 600 scientists, researchers and business experts. It houses a significant and sophisticated laboratory infrastructure.

The Alberta Research Council operates the AERI/ARC Core Industry (AACI) program to develop technology for the recovery of in-situ bitumen and heavy oil. The focus is on recovery methods with improved economics and associated environmental benefits. AACI is a consortium research program managed by ARC. The consortium has 13 paying industry members plus one industry member providing in kind contributions. Industry contributions fund about one third of AACI's $3 million annual operating budget. AERI and ARC fund the remaining budget at a level of one third each. AACI is now in its 18th year of operation.

In addition to AACI, the Alberta Research Council conducted a small amount of oil sands publicly funded research.

Figures 44 to 47 show analysis results for the Alberta Research Council. Over the five years covered by this study, ARC conducted $12.2 million of publicly funded bitumen and heavy oil research. Over 90% of this amount, or $11.5 million, was for applied research. In keeping with the mandate of AACI, over 98% of this research was dedicated to recovery and follow-up technologies. The AACI program is dedicated to the recovery of in-situ bitumen and heavy oil deposits. As a result, no research was conducted for mineable reservoirs. A significant amount of work was directed at primary production, current SAGD and CSS and shallow reservoirs. In response to industry needs, ARC directed its research at reducing energy intensity ($3.4 million), reducing water usage ($3.5 million) and accessing low-pressure reservoirs ($3.4 million).

Figure 44 – ARC and AACI Bitumen and Heavy Oil Research by Research Stage

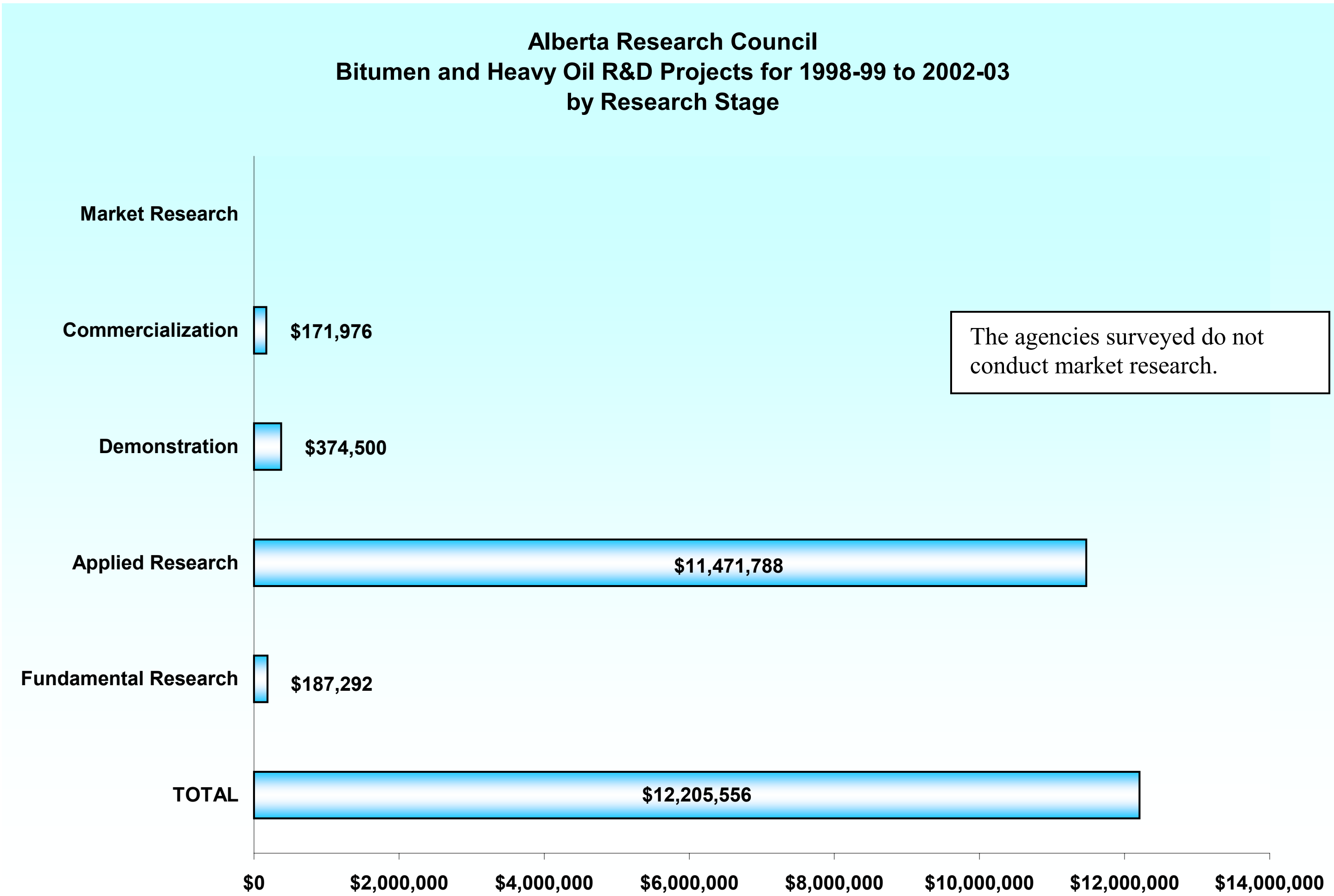


Figure 45 – ARC and AACI Bitumen and Heavy Oil Research by Life Cycle Stage

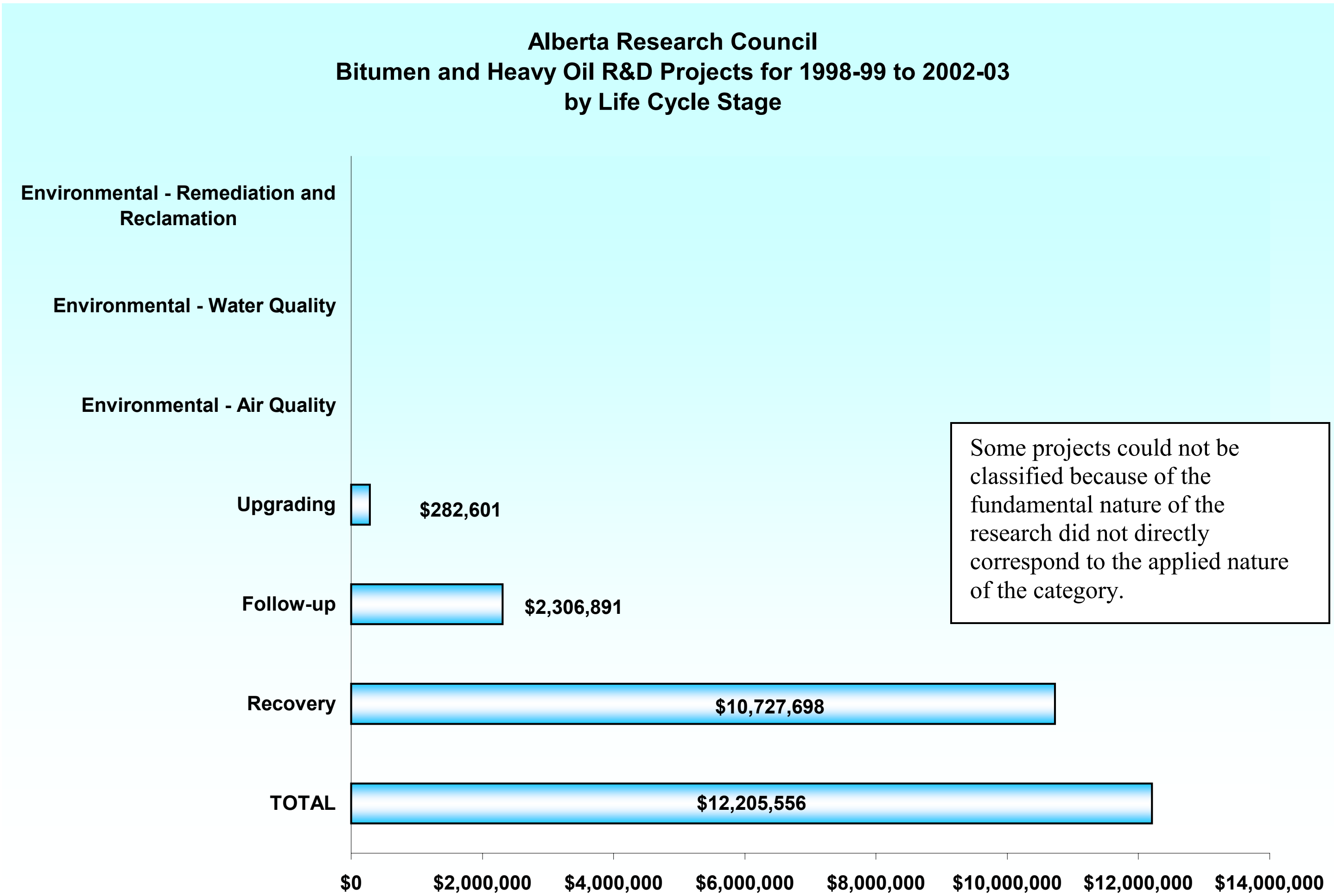


Figure 46 – ARC and AACI Bitumen and Heavy Oil Research by Major Reservoir Type

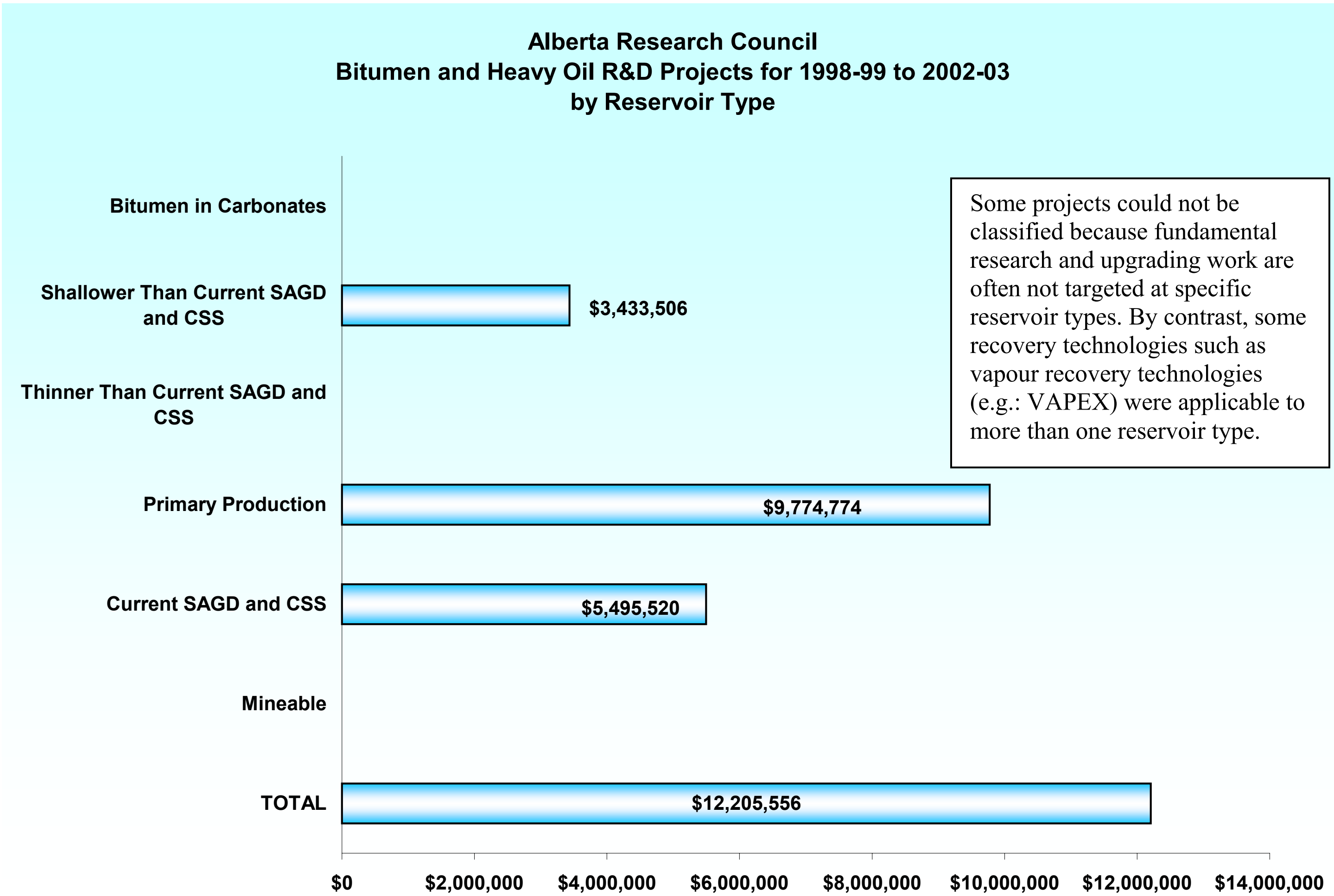
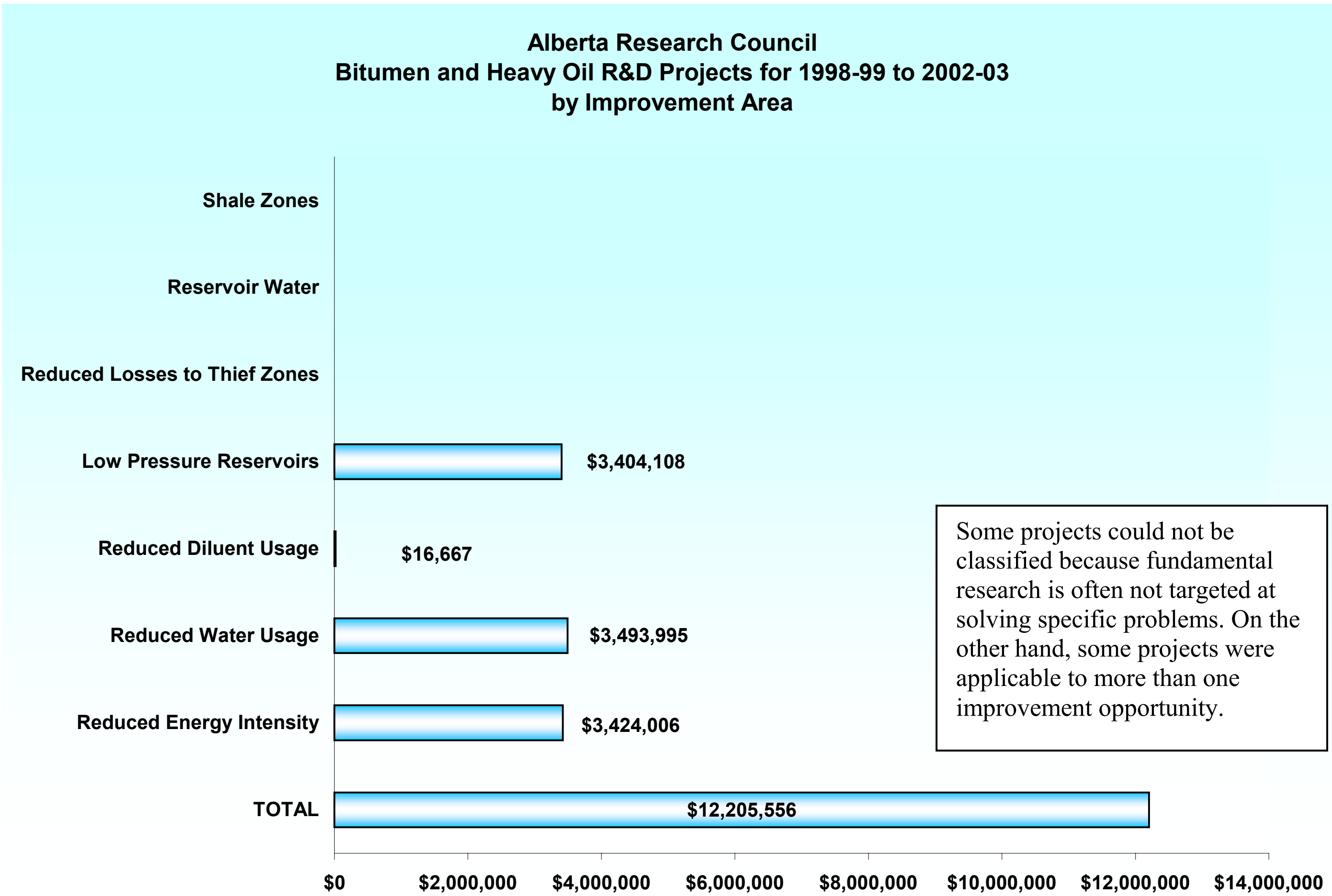


Figure 47 – ARC and AACI Bitumen and Heavy Oil Research by Improvement Opportunity



National Centre for Upgrading Technology

The National Center for Upgrading Technology (NCUT) conducts research in heavy oil and bitumen upgrading. It was formed in 1995 and is a partnership between the federal government and the Alberta government. NCUT provides science and technology to improve energy efficiency and reduce greenhouse gas emissions in the heavy oil and bitumen upgrading and refining industries. Research is focused on converting bitumen into synthetic crude oil and fuel products to meet consumer demand and expectations. Research programs are conducted in three main areas:

- Field and partial upgrading: research aimed at developing partial upgrading technologies that can be implemented at remote field production sites to lower the viscosity and density of bitumen and heavy oil in order to improve transportation to the refinery.
- Primary upgrading: projects targeted at making upgrading a more attractive business investment in Canada by developing lower cost and more energy efficient breakthrough technologies.
- Secondary upgrading: research designed to make synthetic crude oil better suited for processing in North American refinery is in order to improve market access.

NCUT operates over 20 different pilot plants including delayed coking units and hydrocrackers. It also possesses sophisticated NMR and analytical facilities.

Publicly funded research carried out at NCUT was funded by NRCan, AERI, ARC and other government programs. The total amount spent over the last five years was $38.9 million. The analysis is presented on Figures 48 to 51. The vast majority of the research carried out at NCUT is applied research in the amount of $33.4 million. A smaller amount, $5.5 million, was dedicated to fundamental research. Because of its mandate, almost all of NCUT's research is concerned with upgrading of bitumen and heavy oil. A small amount was spent on environmental issues. Because upgrading is concerned with improving the quality of the oil after it has been recovered, the research carried at NCUT is not designed to access any specific reservoir types. With respect to improvement opportunities sought by industry, a small percentage of NCUT's efforts was spent on reducing diluent usage and reducing energy requirements.

Figure 48 – NCUT Bitumen and Heavy Oil Research by Research Stage

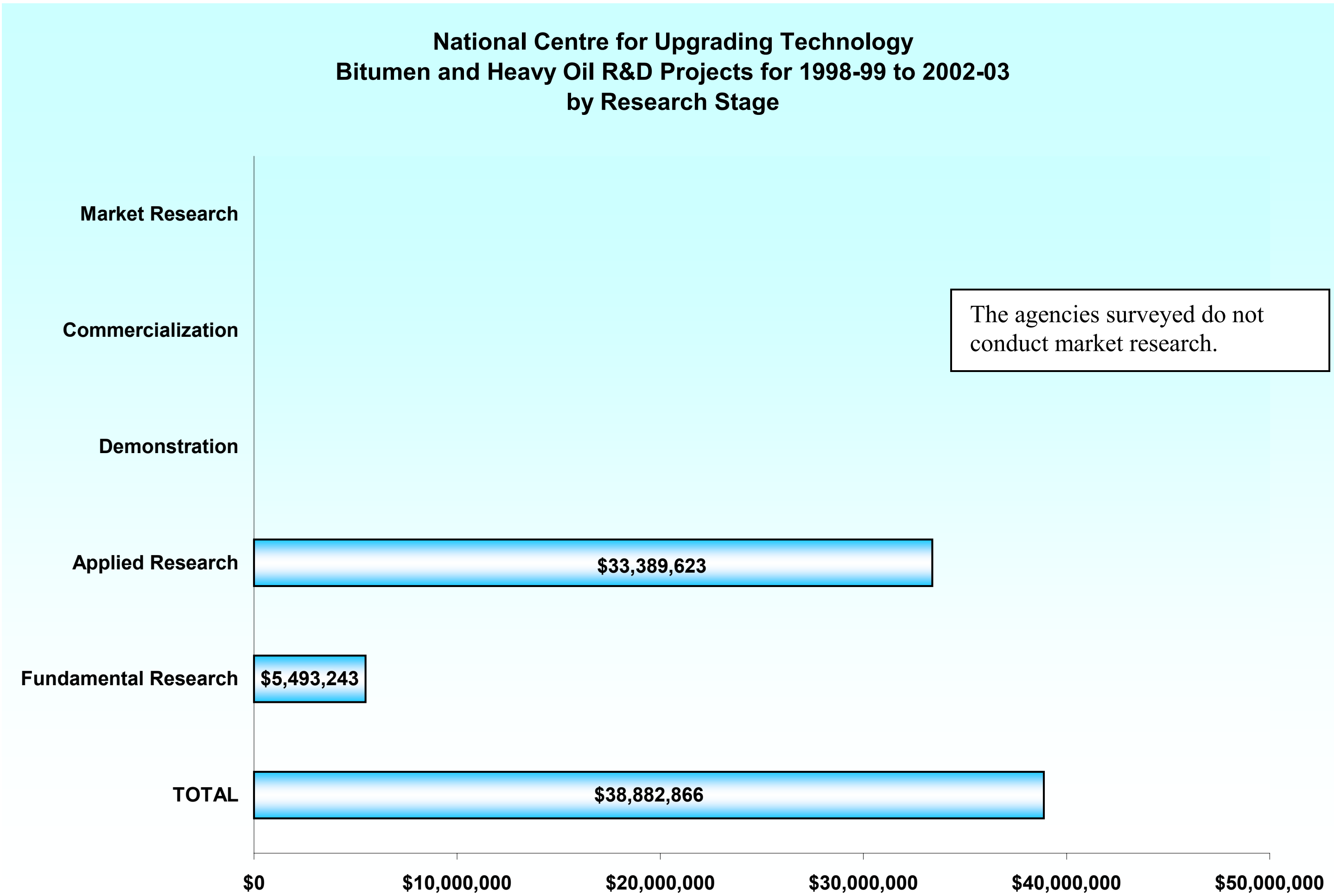
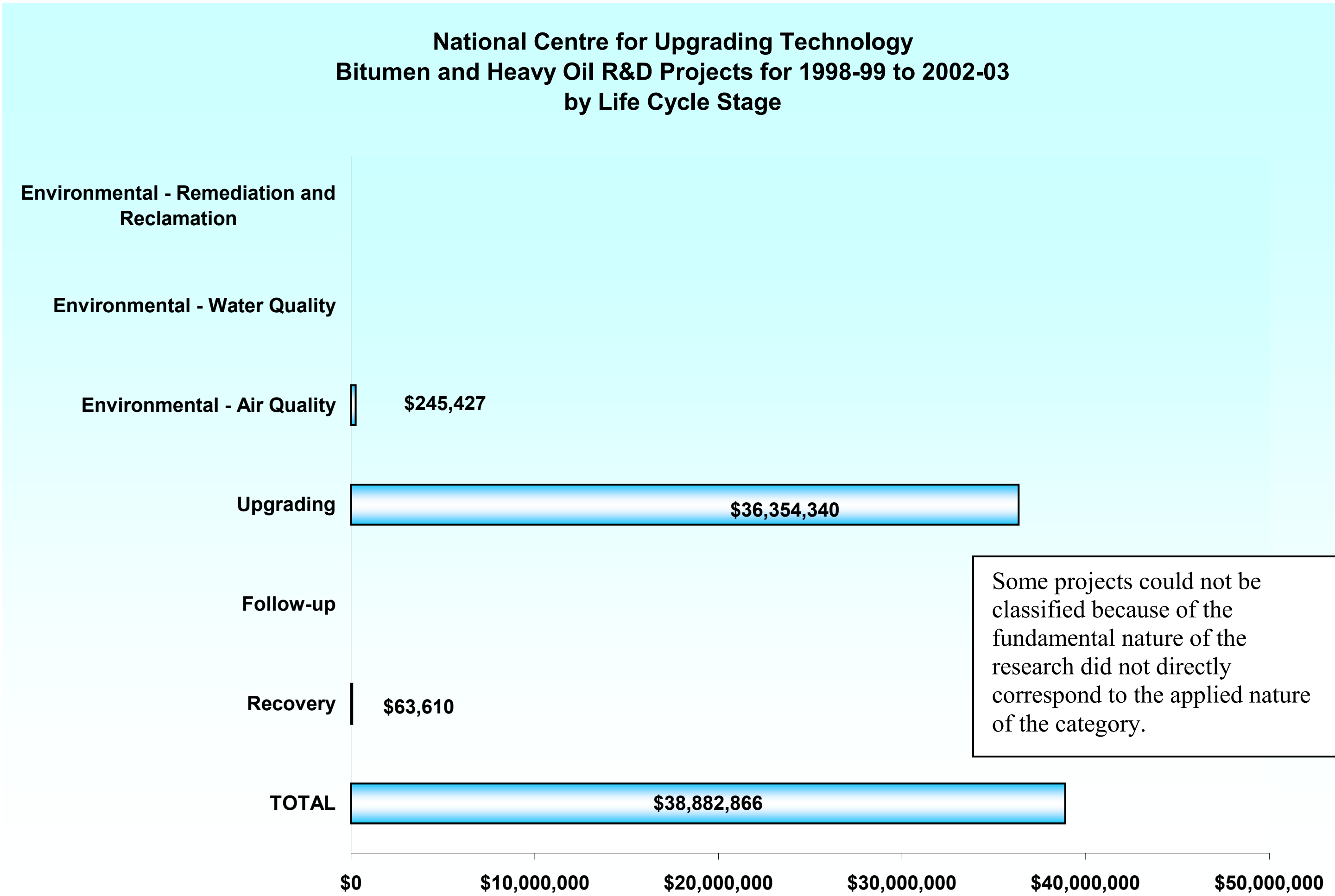


Figure 49 – NCUT Bitumen and Heavy Oil Research by Life Cycle Stage



Some projects could not be classified because of the fundamental nature of the research did not directly correspond to the applied nature of the category.

Figure 50 – NCUT Bitumen and Heavy Oil Research by Major Reservoir Type

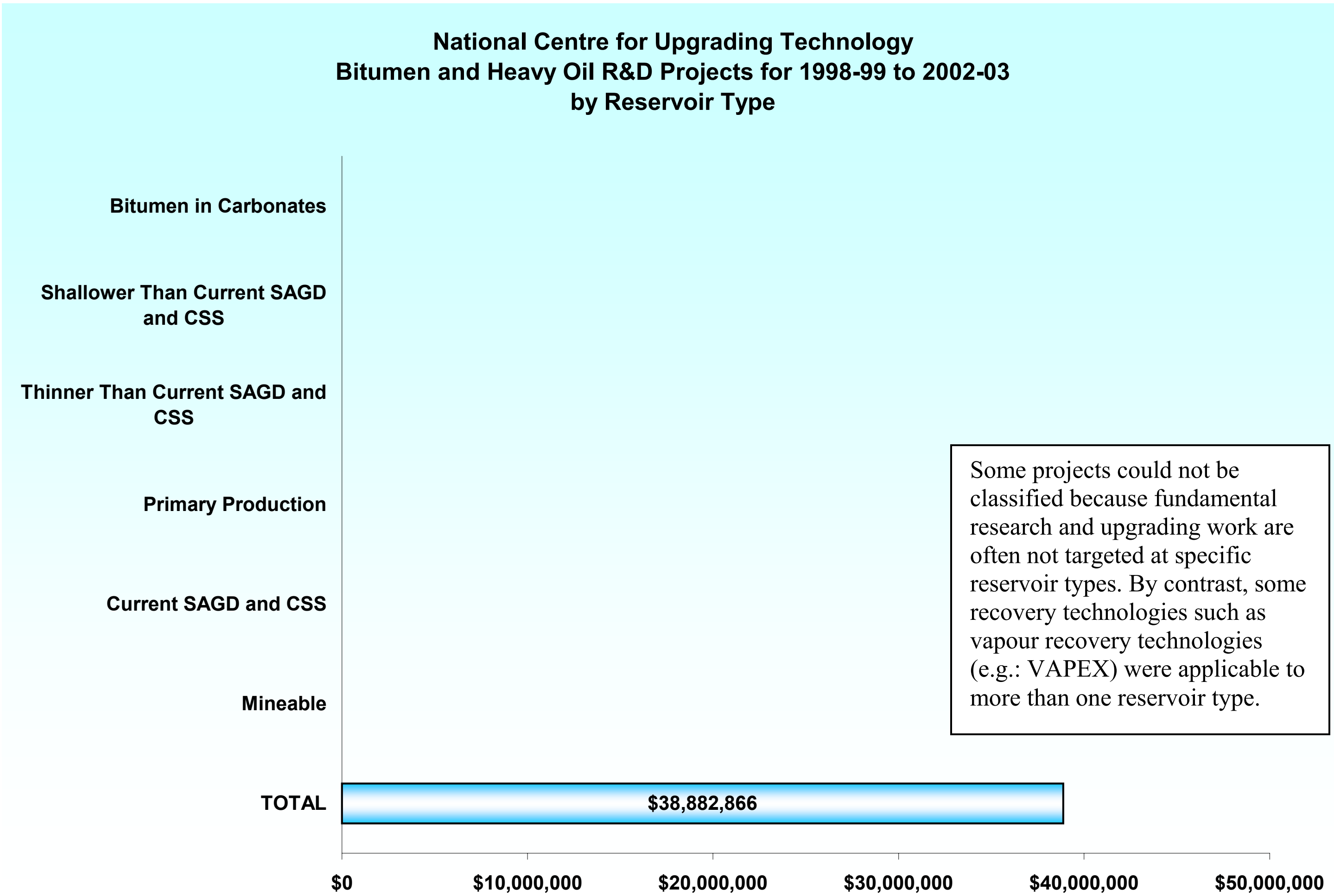
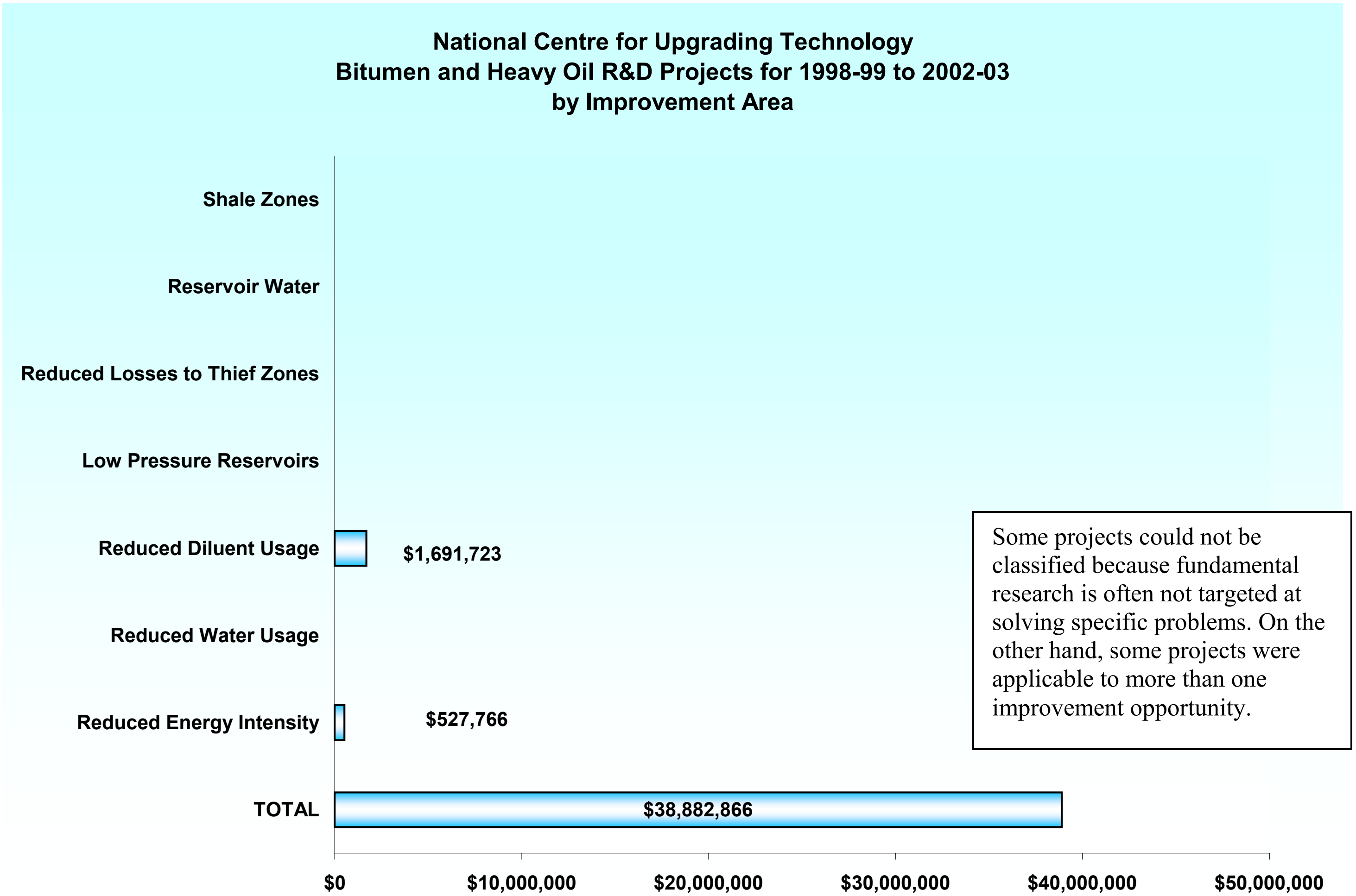


Figure 51 – NCUT Bitumen and Heavy Oil Research by Improvement Opportunity



CANMET CETC - Devon

NRCan's CANMET Energy Technology Centre (CETC) for petroleum research in Devon, Alberta is focused on hydrocarbon supply technologies and related environmental technologies with an emphasis on oil sands and heavy oil. CETC Devon is composed of two groups:

- The National Center for Upgrading Technology (NCUT)
- The Advanced Separation Technologies (AST)

NCUT was discussed in the previous section.

The Advanced Separation Technologies group conducts fundamental and applied research to develop and implement separation technologies for the petroleum and environmental industries. It works in partnership with industry to solve separation problems. In particular, AST is an active member of the Tailings Fundamentals Consortium, a program to develop mitigating solutions to tailings disposal issues. It also operates the bitumen froth treatment facility which is used to develop and evaluate improved bitumen froth treatment technologies leading to increased efficiencies in energy and diluent use.

The AST group is a federal effort funded by NRCan and industry.

During the last five years the publicly funded portion of AST research was $18.7 million. As shown in figures 52 through 55, most of the work, or $11.1 million, was for fundamental research and $7.6 million was spent on applied research. The largest share of research funds, or $9.1 million was spent on environmental issues in a large part because of the presence of the tailings research facility in Devon. An important amount, $7.2 million, was dedicated to recovery projects. Because the research conducted at AST is applicable to bitumen and heavy oil once extracted from the reservoir, the research is applicable to all types of reservoir but not specifically targeted at any particular one. Projects that targeted reduced energy intensity received $1.4 million in funding over five years.

Figure 52 – CANMET Bitumen and Heavy Oil Research by Research Stage

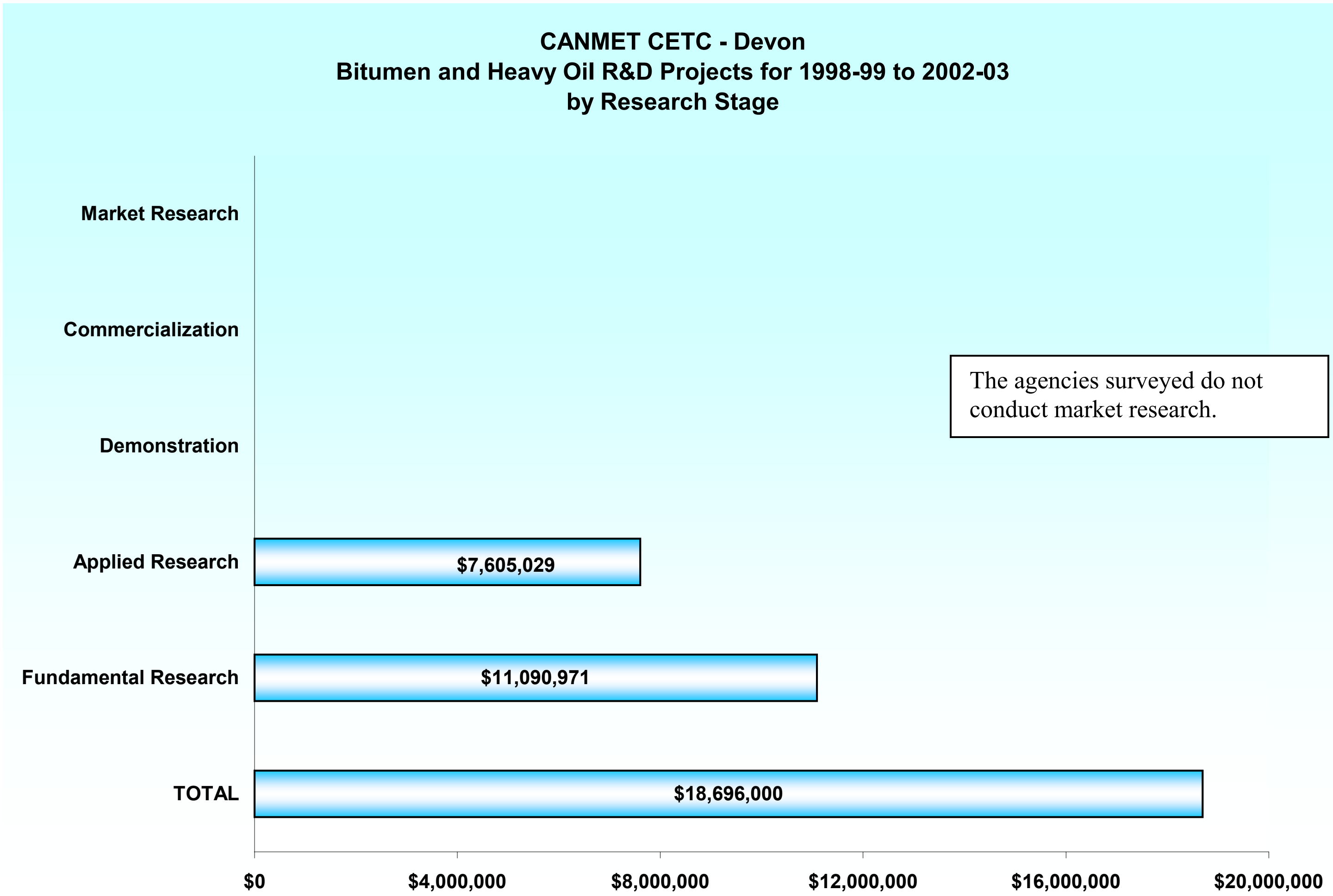


Figure 53 – CANMET Bitumen and Heavy Oil Research by Life Cycle Stage

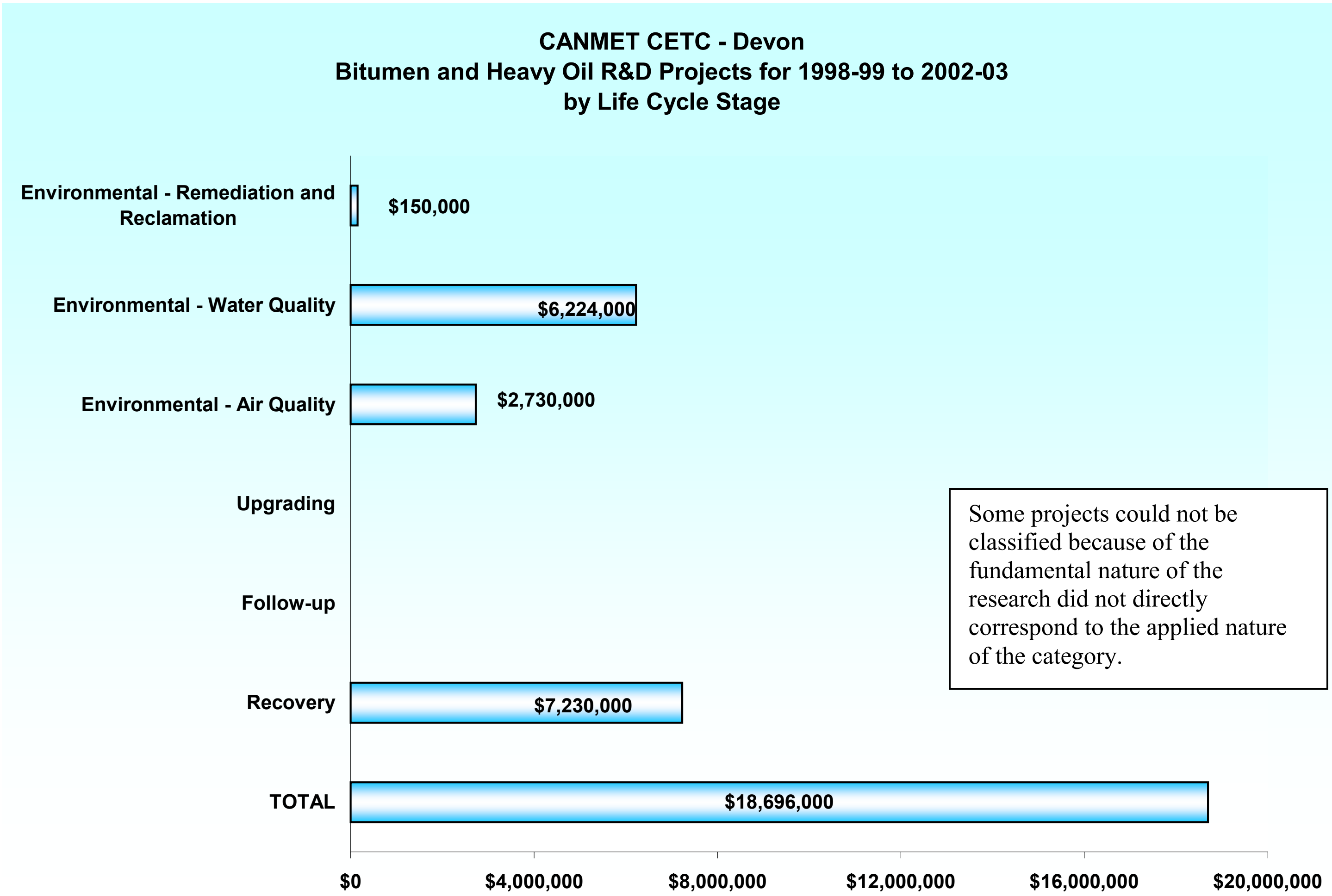


Figure 54 – CANMET Bitumen and Heavy Oil Research by Major Reservoir Type

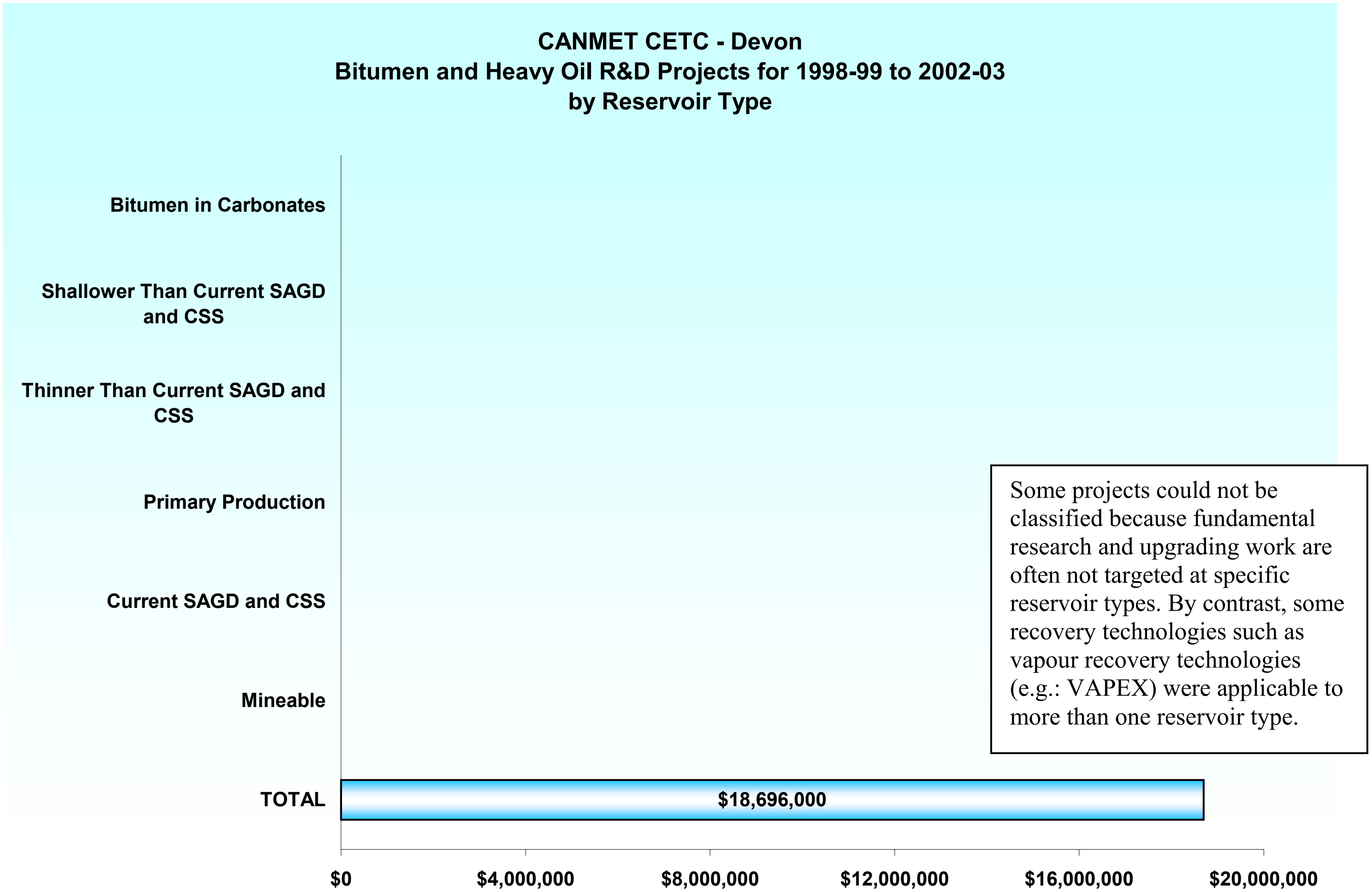
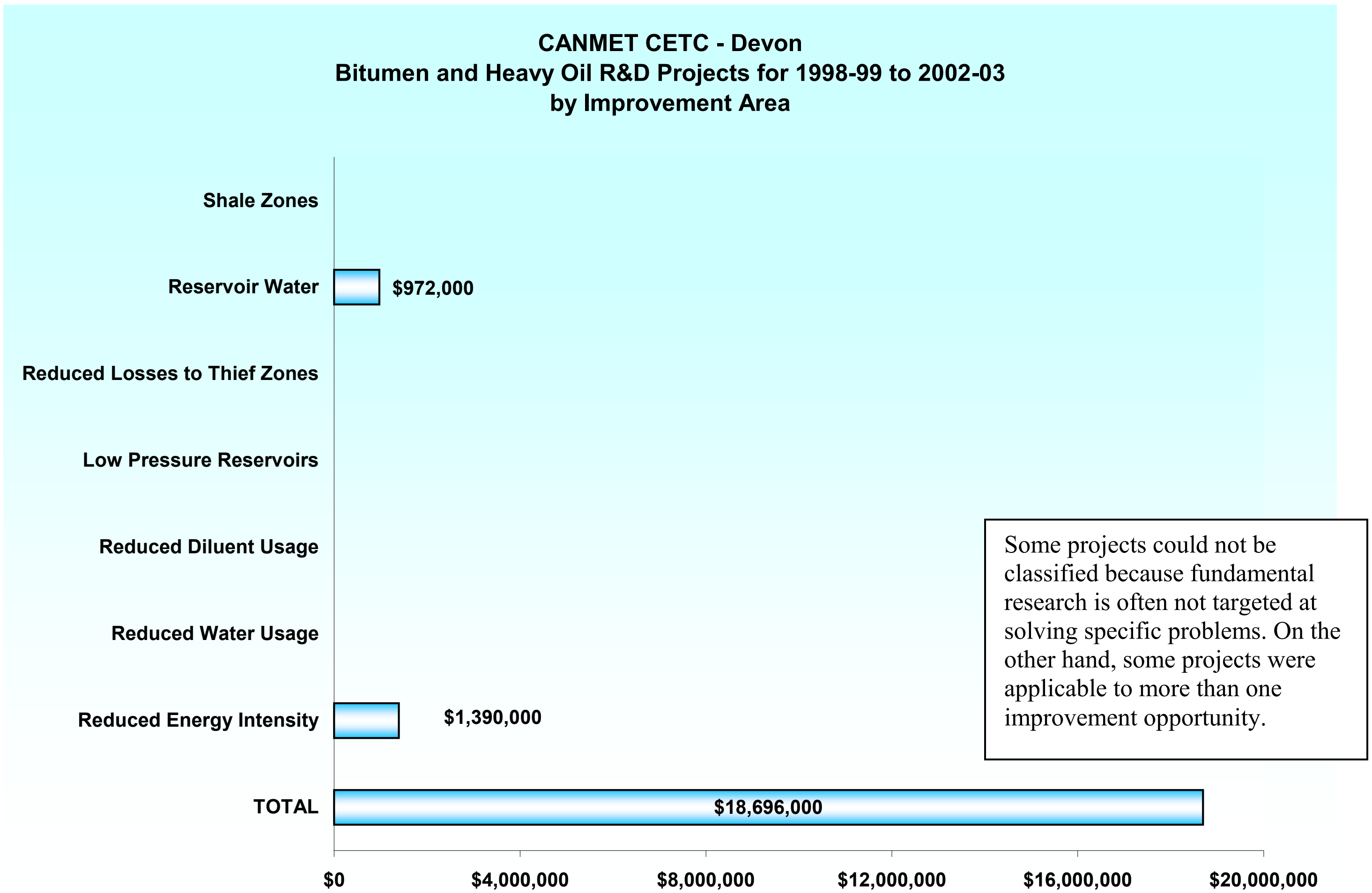


Figure 55 – CANMET Bitumen and Heavy Oil Research by Improvement Opportunity



Saskatchewan Research Council

The mission of the Saskatchewan Research Council (SRC) is to strengthen the economy through research, development, and the transfer of innovative scientific and technological solutions, applications and services.

A collaborative initiative of SRC is the Petroleum Technology Research Centre (PTRC). The Centre is a non-profit petroleum research and development corporation established in collaboration with Natural Resources Canada (NRCan), Saskatchewan Industry and Resources (SIR), The University of Regina, and SRC. The PTRC has financial support from the federal and provincial governments to sponsor research and development projects initially for five years. The PTRC receives support for its research projects from the petroleum industry to complement the support it receives from government.

The focus of PTRC is research and development aimed at enhancing the production and recovery of Canadian petroleum resources by drawing primarily but not exclusively upon the expertise of the Energy Branch of the SRC and the Engineering Faculty of the University of Regina.

Results for the Saskatchewan Research Council are shown on Figures 56 to 59. Most projects were applied research, addressed follow-up issues and were applicable to reservoirs suitable for current SAGD technologies and reservoirs too thin for SAGD technologies.

Figure 56 – Saskatchewan Research Council by Research Stage

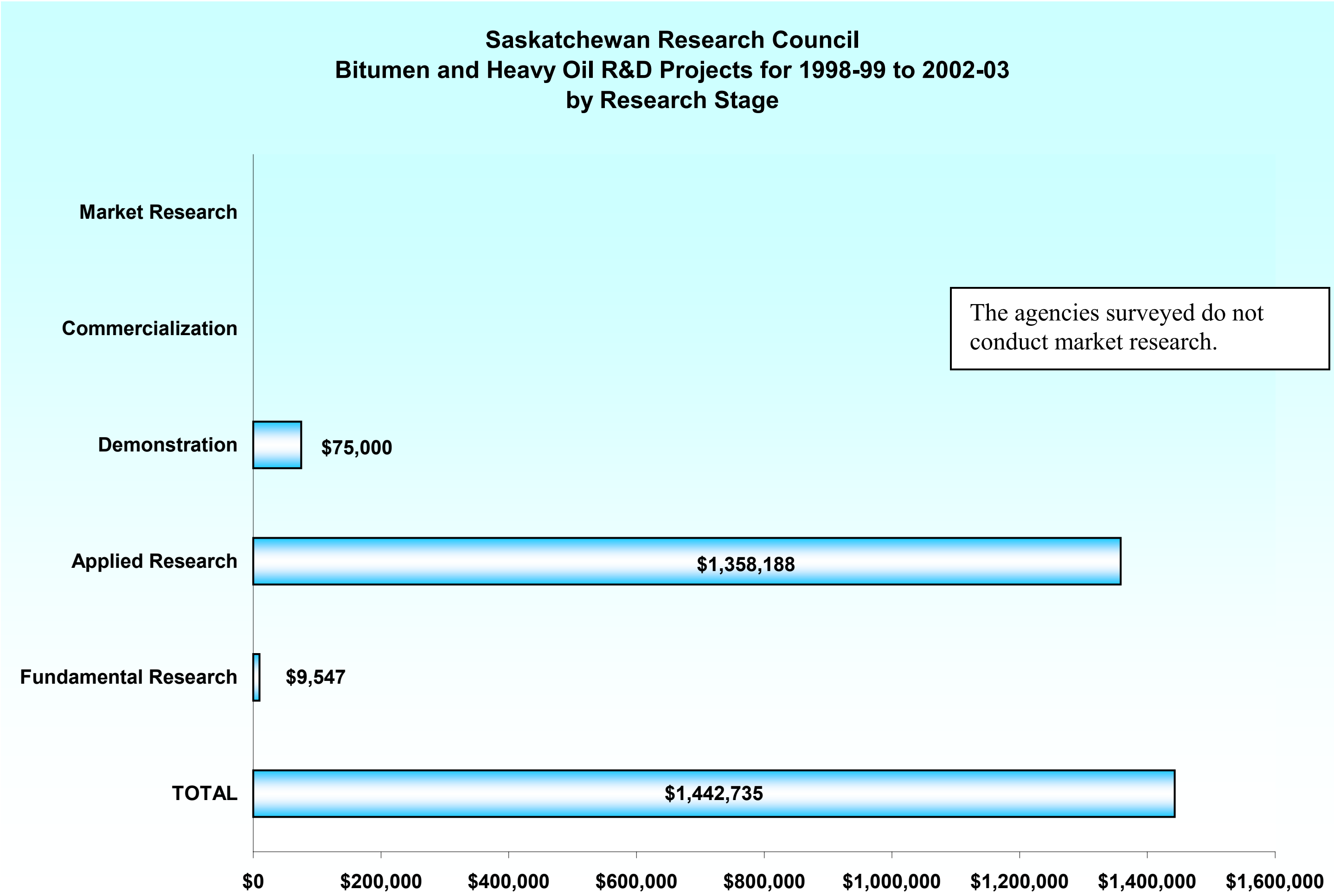
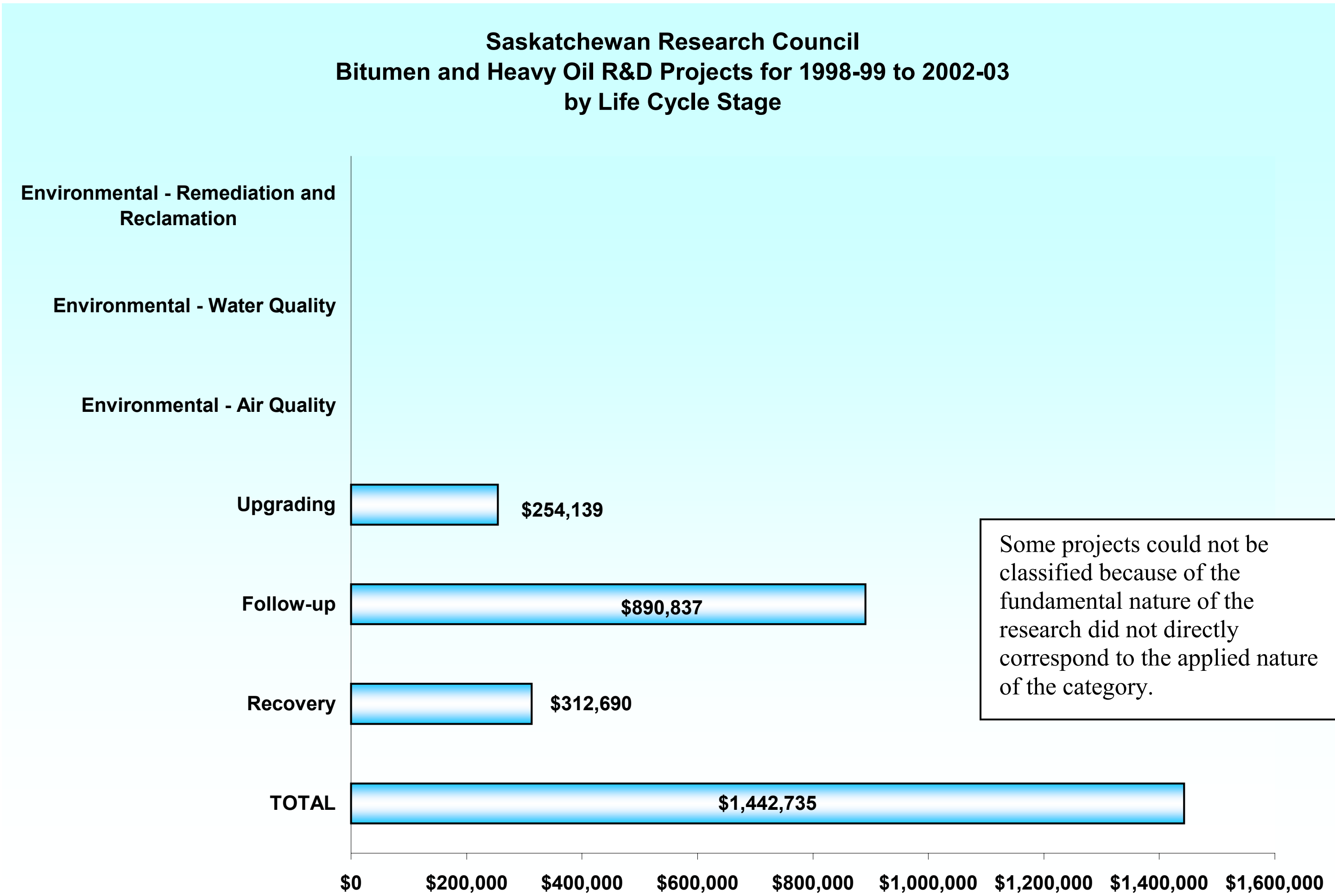


Figure 57 – Saskatchewan Research Council by Life Cycle Stage



Some projects could not be classified because of the fundamental nature of the research did not directly correspond to the applied nature of the category.

Figure 58 – Saskatchewan Research Council by Major Reservoir Type

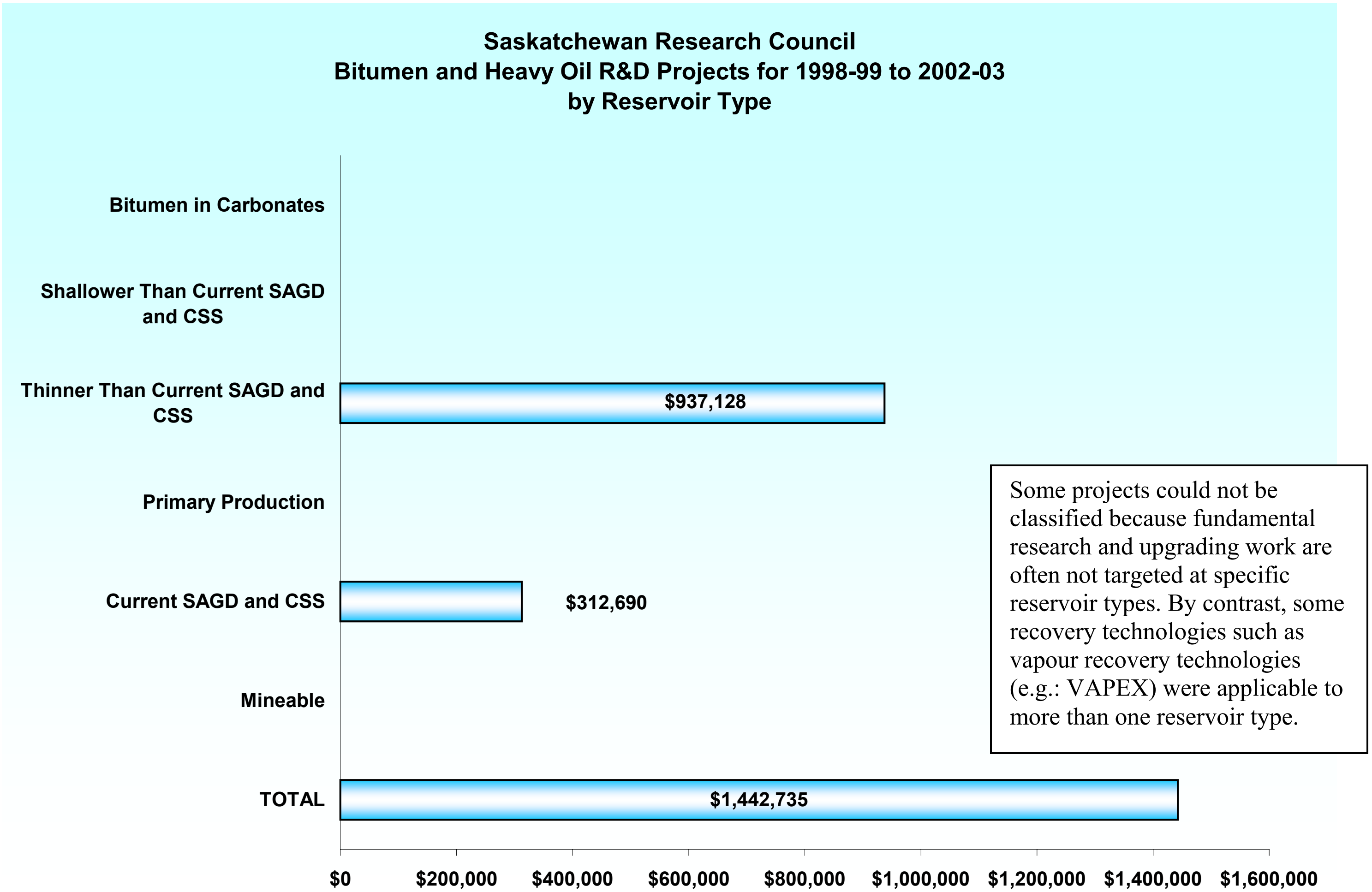
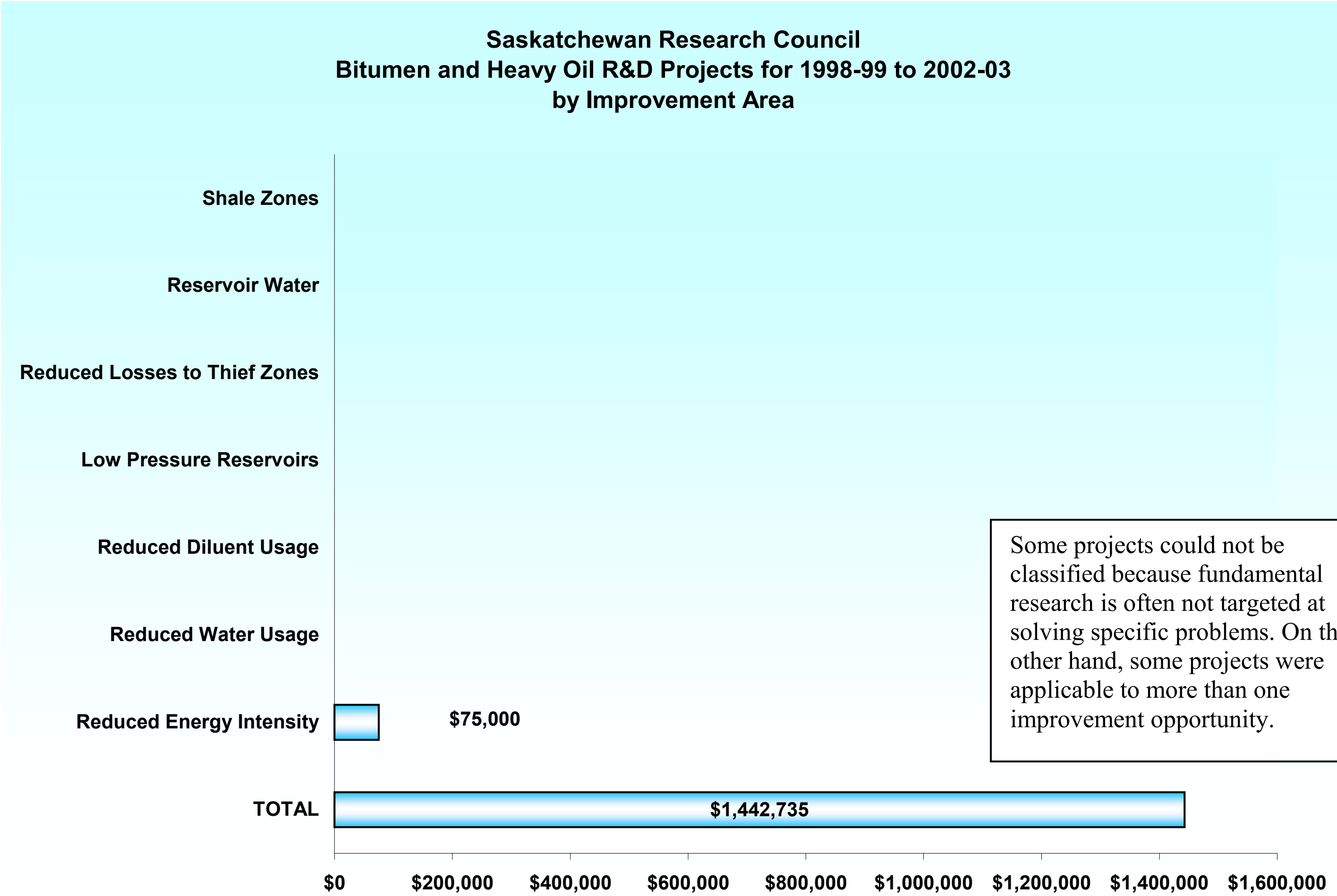


Figure 59 – Saskatchewan Research Council by Improvement Opportunity



Some projects could not be classified because fundamental research is often not targeted at solving specific problems. On the other hand, some projects were applicable to more than one improvement opportunity.

Conclusion

A survey and inventory of publicly funded oil sands research was conducted by obtaining primary information and data from research funding agencies and research organizations. Over the last five years, approximately $117 million, or on average $24 million per year, were directed to oil sands research. Applied and fundamental research received the most funding. With respect to the cradle to grave life cycle stages of resource exploitation, the recovery stage received the most funding. Environmental issues received the least amount of funding. The reservoir types that are currently under active development received more funding than marginal reservoir types.

By a wide margin, the two top funding agencies for oil sands research were Natural Resources Canada and the Alberta Energy Research Institute. Most of the research was conducted at the National Center for Upgrading Technology and at the associated CANMET research facility in Devon, Alberta. The University of Alberta, the Alberta Research Council and the University of Calgary each conducted approximately $12 million of oil sands research over 5 years.

While this inventory of publicly funded research provided useful information about the amount and intent of oil sands research, it provided only a partial picture. In order to construct complete picture of oil sands research, a survey and inventory of privately funded research needs to be conducted and integrated with the present work.

Appendix A - In-Situ Oil Sand Reservoirs Technology Matching Potential Problems

Draft #2

General

1 Mineable oil sand areas and associated problems are not covered here
2 The Athabasca oil sands area is a very heterogeneous reservoir with most oil sand leases containing more than one fault.
3 Some oil sand leases will need to employ more than one recovery strategy in order to enhanced bitumen recovery
4 CHOPS heavy oil production is not part of this evaluation

In-situ recoverable oil sand potential but with the following single fault	Oil Sand Recovery Process	Comments
Reservoir pressure <4 kPa/m depth with no appreciable thief zones present	Reservoir repressure, Repressure and LP SAGD; Repressure LP SAGD and BHP development; Pilot Plant testing will be required	The EUB resent Regional Geologic Study indicates that there are 25 billon barrels of bitumen in contact with a gas cap in the Athabasca oil sand study area and that the average gas cap pressure in this study area is 560 kPaa (460 kPag) At a reservoir pressure this low, gas lift will not work on any oil sand deeper than II 5m, so will be stranded unless the suggested recovery methods are proven to work. It is estimated that this will take a minimum concerted effort of ten years and a billion dollars to determine how much of this stranded Alberta resource can be salvaged.
2 Insufficient waste water disposal reservoir	SAGD; Vapex ??; THAI?? Pilot testing is advised	SAGD operations will need to incorporate zero waste water disposal facilities. Current operations facing such problems are HangingStone, Mackay River and possibly Firebag. The THAI and Vapex processes also produce waste water so would also need to incorporate waste water treating and disposal facilities

3 Oil sand pay thickness < I 5m	LP SAGD, THAI. Pilot testing will be required	Such areas surrounding a thicker SAGD reservoir could be extensively tested to determine economic cut-off oil sand thickness specific to each operating area
4 Absent or insufficient cap rock pressure	Shaft and pillar hydraulic mining Pilot testing will be needed	No such projects have been attempted nor proposed. Potential problems are groundwater contamination from a lack of pressure isolation barrier, ground subsidence and high equipment abrasion wear
5 Top gas> 3m thick with no underlaying water sand present	Repressure gas cap and use conventional SAGD. Piloting is recommended	SAGD without gas cap repressuring may be possible in areas where there are small thin gas caps < 3m thick as long as no top water is also present. Mobilized bitumen tar banking should seal off thin gas sands but tar banking will probably not work for thicker gas sands or gas sands with water sands
6 Thick top gas and water thief zones> 10m combined thickness in communication with thick continuous oil sand pay 30 or more meters thick.	Repressure gas cap and use pressure matching SAGD. Extensive pilot plant testing should precede any commercial oil sand development	The Surmont pilot plant is such an oil sand reservoir that has been struggling since 1997 to test SAGD performance with thick low pressure top gas and water thief zones over a very rich and thick oil sand pay. There have been no attempts yet to repressure the gas cap yet to enhance bitumen recovery performance. This pilot has yet to yield conclusive answers sought. Pilot operations are continuing.
7 Top gas and water> 20m combined thickness	Repressure gas cap and use LP SAGD. Long term pilot testing is needed	Full well life cycle pilot testing will be required to determine if such a project will be remotely economic. Poor cum SOR and bitumen recovery is expected
8 Middle McMurray lean (swept) oil sand zones with <50% bitumen saturation	Low Pressure SAGD	Many oil sand reservoirs have some lean (swept) zones. Operating experience will determine how much they will degrade cum. SOR and economic performance. Long Lake is a reservoir that contains swept middle McMurray oil sand deposits.
9 Bottom transition with several meters of oil sand with low bitumen saturation < 50%	Reservoir pressure matched SAGD? Pilot testing is highly recommended	EnCana encountered a bottom transition high water saturation zone at Foster Creek Phase I area.

10 Bottom water < 20% of oil sand pay thickness	Reservoir pressure matched SAGD.	Piloting would need to precede any commercial development
11 Bottom water> 20% of oil sand pay thickness	Pressure matching SAGD?? Vapex??; THAI??	Tucker Lake and Muriel Lake are two examples of bottom water failures using CSS in the 80s. Husky believe that they can make SAGD work at Tucker Lake. Time will tell how economic it will be. Injection/production mass balance control will be crucial for them
12Top and bottom water thief zones present	Repressure gas cap then use pressure matching SAGD?? Vapex??; THAI??	Christina Lake is an example of an oil sand reservoir with both top and bottom thief zones. It will be very tricky for EnCana to make this operation work economically
13 Horizontal shale barriers < 1 m thick and not laterally connective between delineation wells with a minimum density of one well per LSD (40 acre) spacing	Regular SAGD operation	Should have regular SAGD performance with some small degradation of performance caused by minor drainage impairment
14Horizontal shale barriers >2m thick and connective between delineation wells with a minimum density of one well per LSD (40 acre) spacing	SAGD for each zone> 10m and preferably I 5m thick	It is unlikely that there will be any potential areas with more laterally than two pay zones thick enough to exploit
15 Oil sand > 20m thick with a high brechia content	SAGD	The brechia will rob some heat reducing the SOR but otherwise is thought to pose little other recovery problems
16 High TDS basal water	Reservoir pressure matching SAGD	Large disposal reservoirs exist in the Cold Lake oil sands area but not in the Athabasca oil sands area. Vapour recompression water treating is not proven and high cost option
17 High TDS make-up water	SAGD; THAI??; Vapex ??;	Either a large water disposal reservoirs is available or zero waste water discharge salt removal will be required. Salt removal by brine concentration processes have not been proven up yet

18 Bitumen saturation < 65%	Poor SOR SAGD; THAI??	65% bitumen saturation may be O.K. for the Cold Lake area, don't know for the Athabasca oil sands reservoir
19 Multiple stacked pay each < 10m thick separated by shale barriers	Stacked SAGD well pairs	High Capital and Operating costs with poor economic performance
20 Lean (swept) oil sand zones with <50% bitumen saturation	THAI?? Or VAPEX??	Poor recovery and high cum SORs are expected. Economic performance will depend on what fraction of the pay zone is lean and upon other factors
21 Porosity < 30%	CSS in Cold Lake reservoirs. Athabasca area??	Reservoir will probably have low permeability too
22 Permeability < 500 mD	CSS	CSS may be O.K. for Cold Lake area but has not been successful in the more viscous McMurray oil sand reservoirs
23 Permeability < 200 mD	CSS	Will likely be a problem even for Cold Lake reservoirs. Poor recovery performance and high SORs are expected
24 Quaternary channels	Pressure matching SAGD with a suitable buffer set-back from the channel. Shaft and pillar hydraulic mining of the buffer resource??	Some Quaternary channels have eroded down into or through the Manville Group. This has compromised the cap rock pressure containing integrity so could act as a thief zone or worse could enable a steam blow outs even with careful operator surveillance. Such cannels exist on the Long Lake and Mackay River leases

Source: Alberta Department of Energy, 2004