

加拿大的CCUS经验积累 与 中国的CCUS机遇

CCUS Experiences in Canada
and Opportunities in China



墨 镍 总裁兼首席执行官 / 于泽伟 顾问

Mike Monea, CEO / Zewei Yu, Advisor

碳捕集利用与封存知识国际中心 (加拿大)

碳捕集利用与封存知识国际中心

The International CCS Knowledge Centre

组织架构 Organization:

- 非盈利组织 A Not for Profit Corporation with
- 独立董事会监管 An Independent Board of Directors

发起人 Sponsors:

- 必和必拓集团—出资(2千万) BHP Billiton – Funding Sponsor (20 million for 5 years)
- 萨斯喀电力集团—技术知识支撑 SaskPower – Knowledge Sponsor

愿景 Vision:

知识中心拓展的项目将有助于有关方面深入了解CCUS技术应用的各种“真实”考量因素，推广CCUS可靠的解决方案的实用知识。 Projects undertaken at the Knowledge Centre will help inform stakeholders regarding “real world” considerations in the use of CCUS and advance the practical knowledge of CCUS as a viable solution.

碳捕集利用与封存知识国际中心

The International CCS Knowledge Centre

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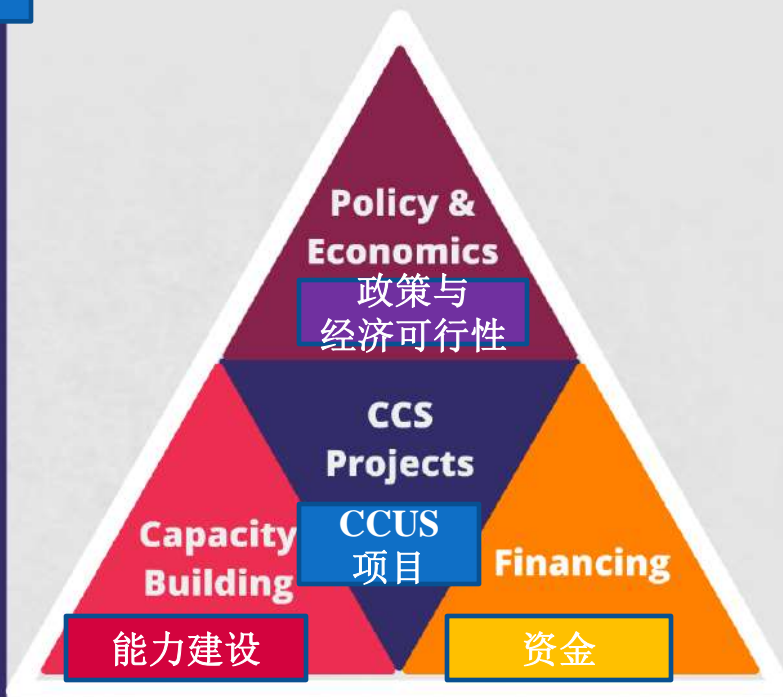
THE INTERNATIONAL
CCS KNOWLEDGE
CENTRE



Facilitates in an
advisory role

Based on expertise
and lessons learned

基于实际项目经验
与真知，承担顾问
角色辅助项目实施



使命



MANDATE:

Advance the
understanding
and use of CCS
as a means of
managing GHG
emissions

推动CCUS技术
普及与应用，以
控制温室气体排
放



MISSION:

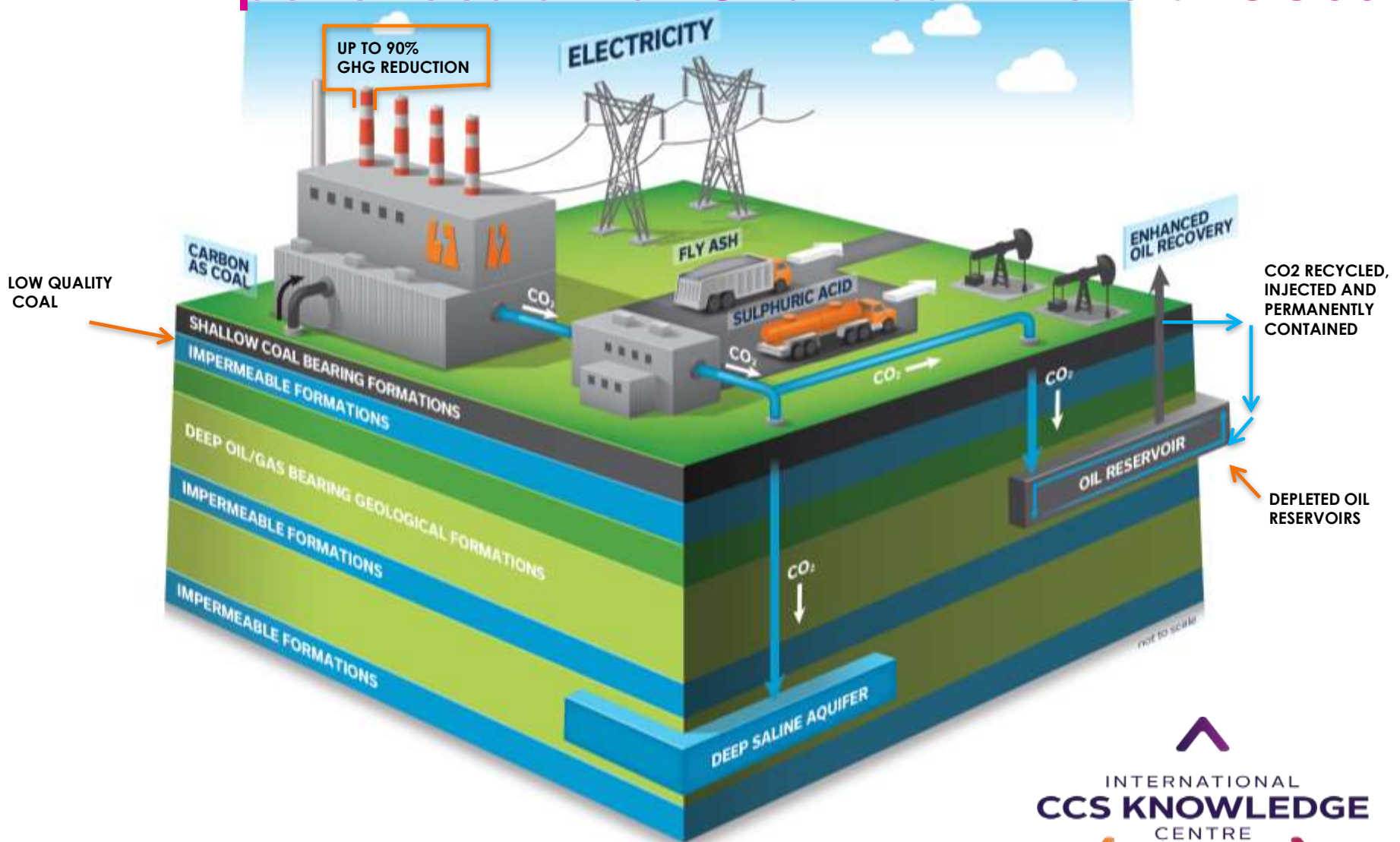
To accelerate
deployment of
CCS worldwide

任务

加速全球CCUS技
术工业化应用

分享知识与经验：加拿大CCUS全流程工业化实践

Experiences of Full Chain commercial CCUS



分享：边界坝电站项目积累的真知与经验

ACCESS : Learnings from Boundary Dam



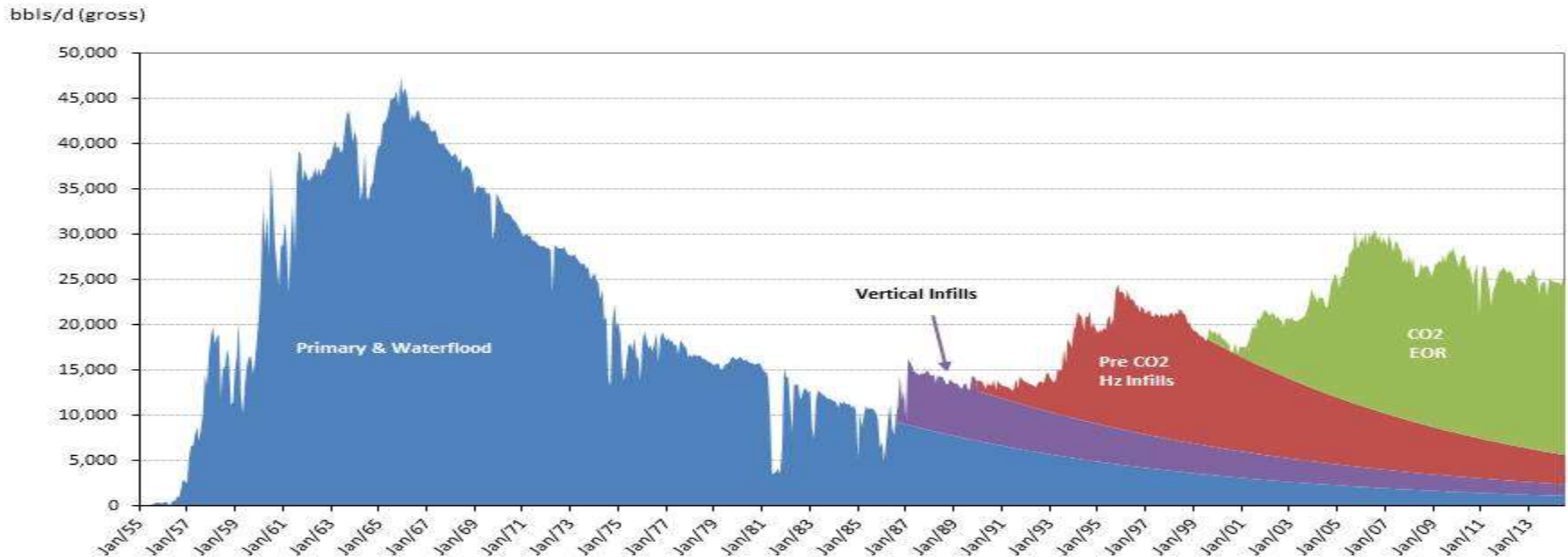
全球首例燃煤电厂
大规模燃烧后碳捕
集与封存一体化设
施: 2016 捕集8500
万吨CO₂, 运行7,
400小时(85%)。

World's first
fully integrated CCS
facility: captured
850,000 t CO₂,
operating 85% of
time in 2016 alone.

经验：加拿大全流程工业化CCUS——驱油 Experiences: ENHANCED OIL RECOVERY (EOR)

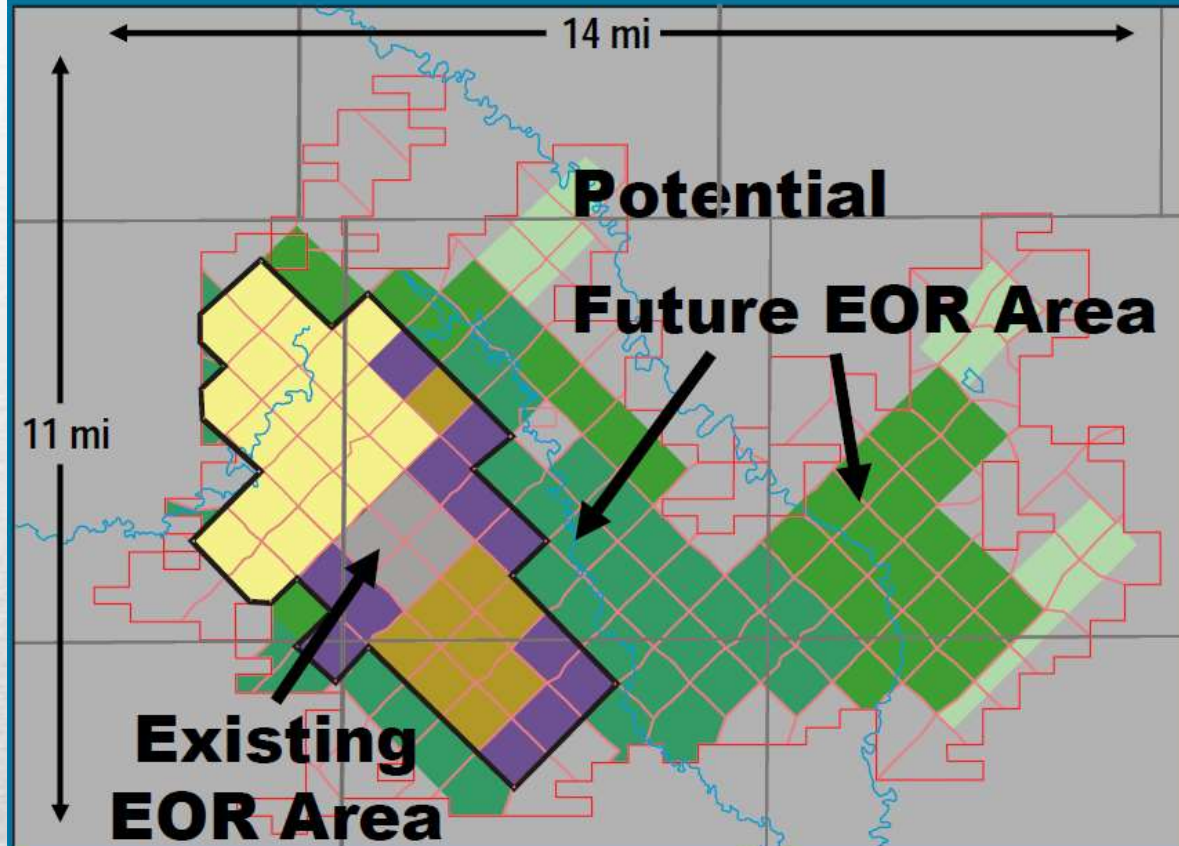
- 日产量高达 **4,500方**, **35年新高**, 二氧化碳驱增采量 占**2/3**(韦本油田)
Up to 28,000 bbl/day: a 35-year high, 18,000 bbl/d (2/3) are due to the CO₂ flood at Weyburn.
- 地面回收再注入, 渐永久封闭 CO₂ recycled, injected and permanently contained.

Weyburn unit oil production

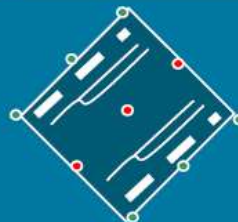


Weyburn CO₂ EOR

Key Statistics



typical pattern



- Discovery: 1954
- ECA WI: 62.1%
- OOIP: 1,400 MMbbls
- Formation: Miss. Midale
- Depth: 4760 ft
- Area: 45,000 acres
- Active Wells: 650 prod. (250 hz.)
289 inj.
- Sour crude: 25 - 34 API
- Cum. Prod.: 389 MMbbl (28%)
- YTD Avg.: 29,686 bbl/d
- EOR patterns in place: 44

CO₂ 提高采收率(2014.8)

CO₂ EOR



- 两个业已商业运行的CO₂ 提高采收率项目
Two commercial CO₂ EOR Projects

- 塞诺沃斯 (韦本) Cenovus Weyburn

- 增产2亿桶 200 million barrels of incremental production

- 业已储存2600万吨CO₂

26 million tonnes CO₂ stored

- 阿帕奇 (米代尔) Apache Midale

- 增产6700万桶

67 million barrels of incremental production

- 业已储存850万吨CO₂

8.5 million tonnes CO₂ stored



分享知识与经验：全流程工业化CCS-副产品利用

Experiences of Canada's Commercial CCS: SECURING OFF-TAKERS.



CO₂ 售予石油公司驱油
Sale of CO₂ to oil company for EOR.



硫酸售予化肥等行业
Sale of sulphuric acid, used primarily for industrial purposes, i.e. fertilizer.



烟灰 售予水泥企业
Sale of fly ash for concrete production.

分享：政府二氧化碳驱油项目鼓励政策

Sask. Government CO₂-EOR Incentives

提高采收率项目资源使用税优惠 EOR Royalty Regime

- 投资成本回收前，仅缴纳毛收入的百分之一或零
 - Before Investment Payout, 0 or 1% of Gross Revenue
- 投资回收后，缴纳收入的8%或20%（毛收入---运营成本）
 - After Investment Payout, 8% or 20% of (Gross Revenue – Operating Cost)

石油新技术应用补贴 Saskatchewan Petroleum Research Incentive

- 补贴石油新技术应用计划费用的30%，最高可抵税三百万加元。

• 结果：石油公司愿意购买更多二氧化碳，扩大二氧化碳驱强化采油规模
Result: Oil Companies would like to take more CO₂ and expand EOR.

• 二氧化碳定义为化学品，现有管控酸气处理的法规适用于二氧化碳注入及管线运输。
CO₂ is defined as chemical and regulations on acid gas is applied to CO₂ injection and pipeline.

加拿大燃煤/燃气热电厂二氧化碳排放标准 REGULATIONS in Canada



加拿大热电厂二氧化碳排放标准 (排放净值)
Canadian Emission Standard for thermal
power units (net)

- **-420公斤/每兆瓦时, 适用所有热电厂
(燃煤热电减排68%)**

-420 KG / MWh-n

applied to new / existing coal (68% capture)
& natural gas plant.

* **2015** 生效, Effective July 2015





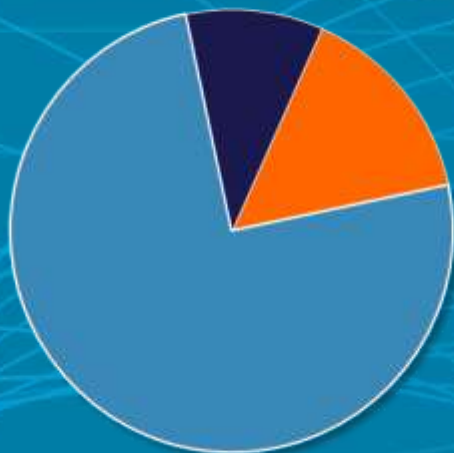
边界坝电站鸟瞰 BOUNDARY DAM

分享知识与经验：比较电价成本CCUS与燃气

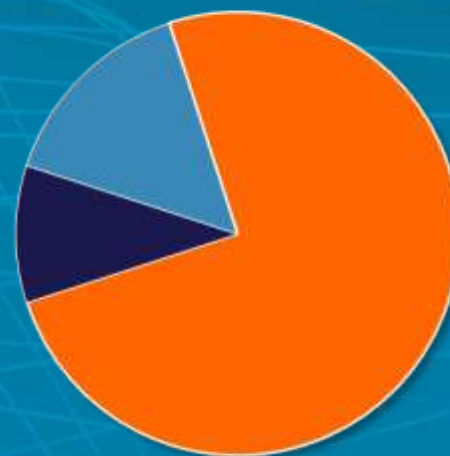
COMPARING COSTS: 30 YEAR LIFE CYCLE, 2010 POINT IN TIME ANALYSIS

30年全寿命周期2010年电价成本

Baseload Natural Gas
Cost of Electricity



BD3 Carbon Capture
Cost of Electricity



- Capital Investment
- Fuel Expense
- O & M

边界坝#3设计效率: 发电, 一体化减排, 水回收

BOUNDARY DAM INTEGRATED DESIGN: CCS, Emission Reduction/ Water Recovery

效率 Performance	捕集前 Pre- CCS	捕集后 Post- CCS	改变 Change
MW 上网电力	139	110-115	-13.6%*
CO₂ (T/Day)	3604 吨/日	360 吨/日	-90%
SO₂ (T/Day)	7.12 吨/日	0	-100%
NOx (T/Day)	2.41 吨/日	1.05 吨/日	-56%
PM₁₀ (T/Day)	190 公斤/日	15 公斤/日	-92%
PM_{2.5} (T/Day)	65 公斤/日	7 公斤/日	-89%
水回收 Water recovered (M ³ / hour)	0	34 吨/小时	+100%



边界坝项目14.67亿加元造价分割-含2.4亿政府前期补助 C\$1.467B BREAKDOWN (\$240M Gov. FRONT END Grant)

电厂改造

POWER PLANT
REFURBISHMENT



Turbine Flue Gas Ducting Boiler Asbestos
更新汽轮发电机，烟气道，锅炉，和清除意外发现的石棉

\$562M CND

新建捕集分厂

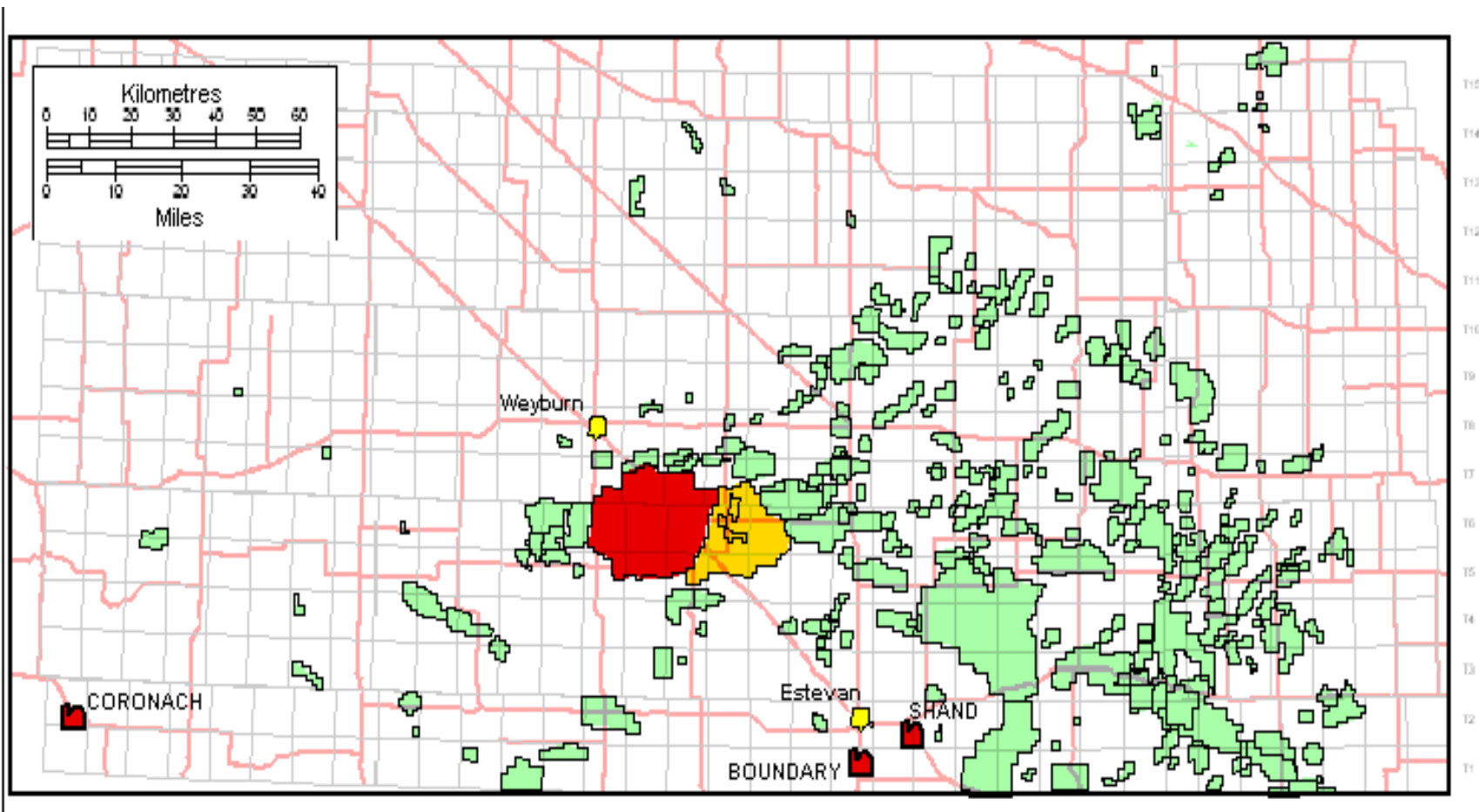
NEW CCS FACILITY



Compressor Absorbers Reclaimers Infrastructure
SO₂/CO₂ 吸收，再生，压缩联合设施

\$905M CND加元

加拿大萨省二氧化碳驱采油机遇 CO₂ EOR Opportunity



加拿大萨斯喀彻温省：碳捕集利用与封存技术创新中心 Saskatchewan: EpiCentre of CCUS Expertise

萨斯喀电力边界坝碳捕集利用与封存一体化工业示范

SaskPower Integrated Carbon Capture & Sequestration
Demonstration Project at Boundary Dam

萨斯喀电力碳捕集技术验证设施

SaskPower Carbon Capture Test Facility

CO₂深层地质封存工业示范项目 (3200米)

Aquistore –Deep Geological CO₂ Storage Demonstration (3,200m)

韦本-米代尔国际能源署CO₂ 监测与封存工业示范

IEA Weyburn-Midale CO₂ Monitoring & Storage Project

重油藏CO₂ 驱油与封存先导示范

Sequestration piloting in Heavy Oil Reserves

CO₂ EOR /
(SRC/Husky Energy)

加拿大二氧化碳地质封存标准/最佳实践手册

The Canada
standard for CO₂ geological storage based on the CCS best practices

CCS知识国际中心 International CCS Knowledge Centre

加拿大石油技术研究中心

Petroleum Technology Research Centre (PTRC)

萨省研究院

Saskatchewan Research Council (SRC)

加拿大能源与环境首席科学家 团队 (里贾纳大学)

University of Regina-Canada Research Chair-Energy & Environment



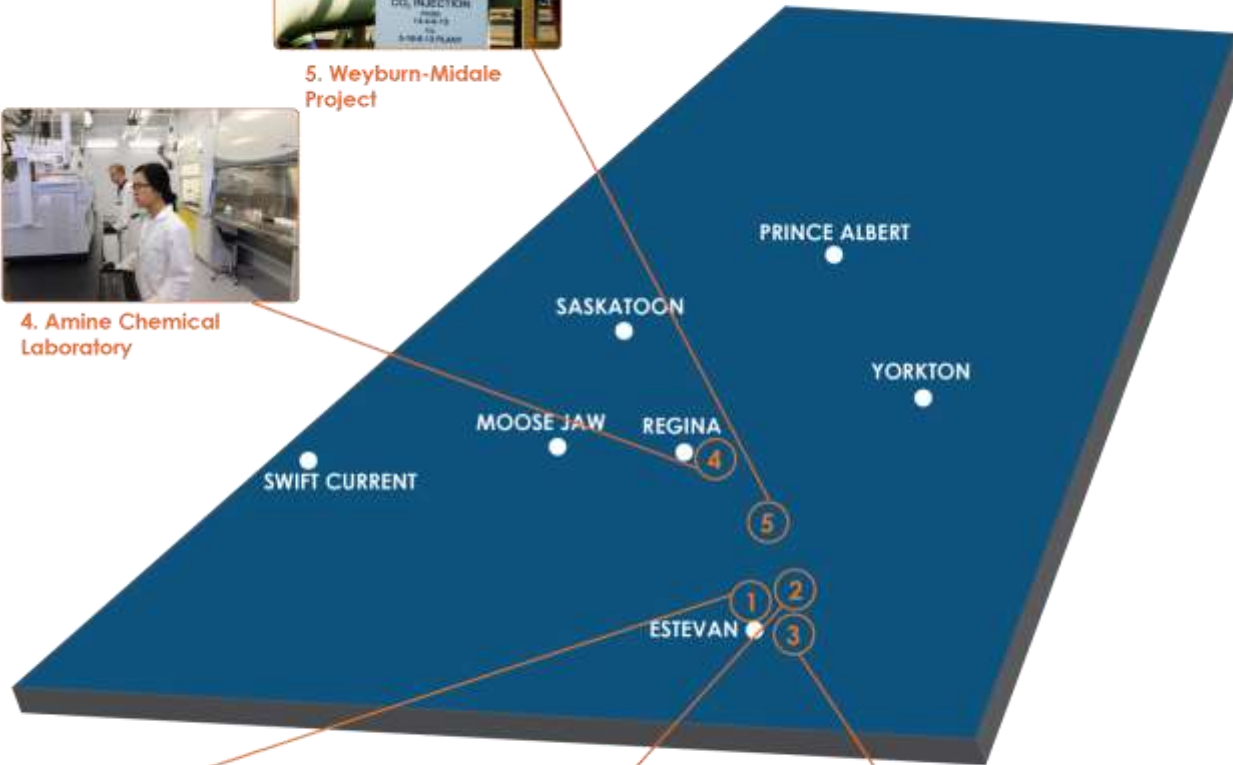
SASKATCHEWAN, CANADA EPICENTRE OF CCS EXPERTISE



5. Weyburn-Midale Project



4. Amine Chemical Laboratory



1. The Boundary Dam CCS Project



2. Carbon Storage and Research Centre (Aquistore)



3. Carbon Capture Test Facility (CCTF)

加拿大全流程工业化CCUS：深层地质封存 AQUISTORE Project



深藏二氧化碳于地下**3.2公里**，（注入井与监测井 各一）

Storing CO₂ 3.2 km underground at SaskPower's Carbon Storage Research Centre (an injection well and a testing well)

2015年4月开始注入， 累计注入10万吨

100,000 tonnes has been injected since April 20-15

石油技术研究中心利用地震成像技术以及永久传感器相阵， 独立监测二氧化碳地下封存状况， 并评估各种检测设备的有效性

PTRC will independently monitor the CO₂ movement and measure the efficacy of various measurement technologies, including permanent array for 3D seismic imaging

- 萨省自2000年启动在维本-米代尔油田全球最大规模受监测的EOR工业化运营， 积累了经验， 15年累计注入3000多万吨
Saskatchewan has experiences with storage due to the Weyburn-Midale project. Approximately over 30 million tonnes of CO₂ stored and monitored since 2000.
- 地质封存受萨省环境部依法监管
Storage is regulated by the Ministry of Environment

加拿大全流程工业化CCUS：碳捕集技术验证设施最新设计

SaskPower Carbon Capture Test Facility

30万千瓦尚德火电站内

Located at SaskPower's 300-MW coal-fired Shand Power Station



为技术供应商提供开放便捷, 经济且中立的开放平台, 在商业运营的环境下验证并优化燃烧后捕集技术

Open, convenient, affordable, neutral and open platform to verify and improve post-combustion technologies in commercial setting

基本实验捕集能力为**120**吨CO₂/日 Primary test unit CO₂ capture capacity of 120 tonnes per day

首先验证日立-三菱电力公司的胺捕集技术 Hitachi-Mitsubishi Power System's proprietary amine technology is the first being tested currently

克服障碍：实施全球工业化CCUS项目

Broke Barriers to Large-scaled CCS Demonstration

- 出于技术与造价的风险考量，选择燃烧后捕集，放弃富氧燃烧（2007-08），立足于优先改造现有煤电基础设施：10+余年研发/技术选择

Selected post-combustion capture over oxyfuel for high capital and technical risks (2007-2008) , targeting existing coal power infrastructure : 10+ years of CCS development / technology screening

- 未来项目须记取的重要教训与运行经验，降低造价与风险
- 资源化利用/ 抵消一定成本， 强化经济论证， 落实重大工业化创新实践

Key lesson for future project, experiences of operation to reduce risks and costs

Sale of CO₂ for EOR and SO₂ / fly ash offset costs and strengthened the business case to enable the project

全球清洁能源低碳发展树立了样板和激励大规模工业规模示范与支持政策与能力建设

Set a reference model for clean low-carbon energy development globally and encourage further large-scaled commercial demonstration project and facilitate capacity building as starting point

中国-加拿大：国际合作机遇

CANADA-CHINA: OPPORTUNITY FOR INTERNATIONAL COOPERATION

- 通过合作借鉴加拿大 **CCUS** 知识与实践应用于大规模工业示范项目， 开创设备制造和创新人才优势。 Collaborate for applying CCUS expertise of Canada to large scale demonstration project, creating advantage in manufacturing capacity and innovative talents in China.
- 有利于实现已列入国家**13-5** 能源创新规划示范与攻关的燃烧后**CCUS**目标 Large-scaled post-combustion CCUS integrated with storage listed in 2016-2020 national plan as intensive R&D (G24) and Demonstration projects (S18).
- 煤电利用不足， 供给侧调整也成为**CCUS**创新的机遇。 以**20%**的能耗， 天然气发电碳排放的**1/4**， 更低成本。 Supply side adjustment provides opportunity for doing CCUS while there is coal power capacity surplus. With 20% parasitic load, CCUS is cheaper, 3 times cleaner than NG.



趋势与机遇：加中国际合作

MOMENTUM & OPPOTUNITIES: CANADA-CHINA COLLABORATION

- 在中国通过工业化示范有可能像太阳能和脱硫技术一样有低能耗与低成本突破，改变**CCUS**大格局。
China is likely to change the game by demonstrating CCUS, with low-cost & low-energy break-through, as in solar and SO₂ removal technologies.
- 加-中合作有助于培育**CCUS**产业链，作为跳板和一带一路战略的组成部分，利于全球应对气候变化。
Canada and China join force to help foster CCUS industry chain as spring board and component of the Belt & Road Initiative to benefit the world in fighting climate change .
- 加拿大与中国承诺“创新使命”义务，加倍注资减排创新技术项目。
Canada & China committed to Mission Innovation to increase funding to technological solutions to reduce emissions.



HISTORIC OPPORTUNITY FOR PARTNERSHIP

- **CCUS 工业化项目经验助力/加速CCUS优化与工业示范**

CCUS experience in Commercial Projects help accelerate the development/ optimization and application of CCUS to domestic mega demonstration project:

- **推动烟气分析，污水管控，工程优化，吸收工艺等技术进步，降低CCUS技术应用风险与工程造价。**

advance flue gas analysis, waste water management, construction optimization, absorption methods, and other technical areas related to CCUS, bring down the costs (加拿大造价与新兴经济体国家不具可比性 not comparable with emerging economies) of CCUS technology and deployment projects.

- **带动CCUS 向冶金，水泥与化工行业转移**

Facilitate CCUS application from power industry to energy-intensive steel/metallurgy, cement industries.

- **知识中心堪当项目顾问，为全球CCUS项目服务：**

经济论证

技术评估

操作运行

经验教训

As project advisor, the Knowledge Centre has the capacity to work for any new global CCUS project, including:

- Business Case

- Technology Evaluation

- Operations

- Lessons Learned

趋势与机遇—国际合作

MOMENTUM & OPPOTUNITIES : INTERNATIONAL PARTNERSHIP

• 政策与经济可行性 Policy & Economics:

Consider regulations, international commitments, and social costs:

- 综合优惠政策手段，如减免税收与资金扶持等手段，是启动CCUS示范的基本动力。 comprehensive incentive policy measures such as enabling funding and tax breaks are essential driver for early stage CCUS demonstration.
- 跨行业的CO2利用双赢交易，是CCUS项目可行性的重要因素
CO2 sales for use across oil and Power industry sectors are win-win for CCUS economic feasibility

• 经验分享与培训人员，政策与能力建设（人才培养）

hands-on and help build capacity and develop policy

- personnel training at the cluster facilities
- testing and training at CCTF
- Simulation system

share knowledge, train

• 撬动财政金融 Financing:

The funding institutions financing CCUS especially in developing countries. Ex:

- 绿色气候基金 Green Climate Fund
- 亚洲开发银行 Asian Development Bank
- 创新使命 Mission Innovation initiative

趋势与机遇：国际合作

MOMENTUM & OPPORTUNITIES : INTERNATIONAL PARTNERSHIP

- **CCUS 是降低煤炭排放实现低碳经济的关键，而煤炭占能源组合的40%，温室气体排放量的1/4，短期内煤炭不可能退出历史舞台。**
CCUS is critical to low-carbon economy by reducing CO2 emissions from coal, for coal accounting for 40% of power and 25% of GHG emissions, will not go away for decades.
- **在CCUS有助于能源组可再生能源效率发挥，可再生能源有赖于与化石能源的系统整合（应享有不亚于可再生能源的系统价值与优惠政策. 如: 电动汽车把排放集中留在源头）。**
CCUS helps renewable energy production for renewables is integrated with base-load coal fired power system (CCUS deserves a system value and policy incentive no less than renewable in power mix. Ex. Electric car enjoy incentives and it leave emissions at power source).
- **有助于局部地域能源的一体化系统规划 (如：可再生能源的系统价值与可控清洁化石能源平衡与匹配)**
facilitate a regional integrated resource system planning (system value of renewables vs. CCS base load).
- **在脱硫与脱销已经到位的最佳系统条件下，电厂配备CCUS只需要碳捕集装备的基建投入。**
In the best conditions, where SO2/Nox removal already in place, installing CCUS on a power plant only requires investment in the equipment for CO2 capture,.

趋势与机遇：国际合作

MOMENTUM & OPPOTUNITIES : INTERNATIONALPARTNERSHIP

- 中国的先导示范项目数量最多（驱油，燃烧后捕集）
China has the highest number CCUS piloting projects (EOR and PCC)
- 中国**92%**的火电机组配备了脱硫设备 Over 92% of coal-fired power units have SO₂ removal systems (by 2015, most using limestone)
- 燃烧后捕集工艺要求脱硫，过滤**PM2.5**
Capture process requirement: SO₂ removal/ PM2.5 Removal
- 其它用途值得探索 Other end-use opportunities
 - 干洗剂 dry cleaning,
 - 食油榨取工艺 cook oil extraction process
 - 热交换 heat exchange agent



实践出真知：未来项目可降低造价30%以上
LEARNING STARTS HERE.

OUR NEXT PLANT WILL BE UP TO 30% CHEAPER.

世界权威评价

WHAT THE WORLD IS SAYING

边界坝项目是可以改变你的生活的2014年度10大能源突破之一。---国家地理杂志 文迪.考齐 “Boundary Dam is one of 10 energy breakthroughs in 2014 that could change your life.” **WENDY KOCH, NATIONAL GEOGRAPHIC**

燃煤发电厂碳捕集与封存提供最大的技术应用的机会，边界坝电站项目展示了该技术怎样得以应用。除非我们采用碳捕集与封存技术，否则我们无法实现应对气候变化的长期目标。该项目为我们将该技术直接应用于中国提供了可借鉴的良机。---亚行 阿绍克. 布哈嘎瓦 “CCS on coal-fired power plants provide us the largest opportunity for application, and Boundary Dam shows how it can be done. Unless we do CCS, we’re never going to meet long-term climate change goals. This project provides us an opportunity to learn how we can directly apply CCS in China.” **ASHOK BHARGAVA, ASIAN DEVELOPMENT BANK (ADB)**

只要化石能源与碳密集行业在我们的经济中扮演主导角色，碳捕集与封存就仍然是解决温室气体减排的关键。---国际能源署 玛丽亚. 冯. 德霍文 “As long as fossil fuels and carbon-intensive industries play dominant roles in our economies, carbon capture and storage (CCS) will remain a critical greenhouse gas reduction solution.” **MARIA VAN DER HOEVEN, INTERNATIONAL ENERGY AGENCY (IEA)**

全世界化石能源消费将与我们一起步入2050年。要减排，我们必须掌握达到减排目标的CCS利器。---零排放化石能电厂协会 格蕾美. 思维尼博士 “The level of fossil fuel consumption in the world is going to stay with us all the way through 2050. If we want to take the emissions out, we must have CCS in our armory in order to achieve that objective.” **DR. GRAEME SWEENEY, ZERO EMISSION FOSSIL FUELS POWER PLANTS (ZEP)**



加拿大二氧化碳减排政策举措

Policy Approach to GHG Reduction in Canada

加拿大最近政府宣布**2018**年各省实施全国统一碳价格，收费地方使用。

PM Trudeau recently announced a national 'floor price' on carbon that require all provinces and territories to have some form of carbon pricing by 2018, with revenue staying local.

各省反响不一 Receiving different responses among provinces in Canada:

- 清洁能源为主的省赞成排放限额与交易 (魁省/ 安省); Cap and trade favoured by clean energy dominant economies (Quebec /Ontario);
- 碳税 (阿省---结合专项基金)或 财政中立碳税 (俾诗省); Carbon tax (CO2 intensive-Alberta) or carbon tax neutral (BC);
- 向排放大户收税，投入排放源技术改造(专项基金---萨省). Levy on large emitters to invest in technology solutions (through green fund---Sask.) at emissions source.

担忧： 由于天然禀赋，产业结构，化石能源生产省与纯消费省之间差异，因支付能力不同，统一碳定价或碳税会造成赢家与输家，减排目的错位。

Concerns including:
carbon pricing may create winners and losers simply for different natural resources endowment, and different industrial structure, energy producers versus consumers.

AMINE CHEMICAL LAB

趋势与机遇：国际合作

MOMENTUM & OPPOTUNITIES : INTERNATIONAL PARTNERSHIP

- 2017年6月6日，将与中加两国政府和国际能源署（IEA）协作，主办以推动CCUS 国际合作为主旨的“清洁能源部长会议/创新使命”大会边会。
June 6, 2017 International CCS Knowledge Centre will host CEM/MI side event in Beijing in collaboration with NDRC and IEA
- 2017年7月CCS 知识国际中心承办“IEAGHG第十一届CCS暑期国际学校”。
July 2017, IEAGHG 11th International Summer School on CCS will be hosted by the CCS Knowledge Centre in Regina
- 2017年10月2-7日，在加拿大举办“燃烧后捕集与边界坝CCS项目国际研讨会”
October 2-7, International Symposium on Post-combustion Carbon Capture and Boundary Dam Integrated CCS Project to be held in Regina, Canada.

谢谢！
Thank You

碳捕集利用与封存知识国际中心



墨镍 Mike Monea

mmonea@ccsknowledge.com

www.CCSKnowledge.com
