Advanced Cogeneration Technologies to Reduce SAGD GHG Emissions

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Outline

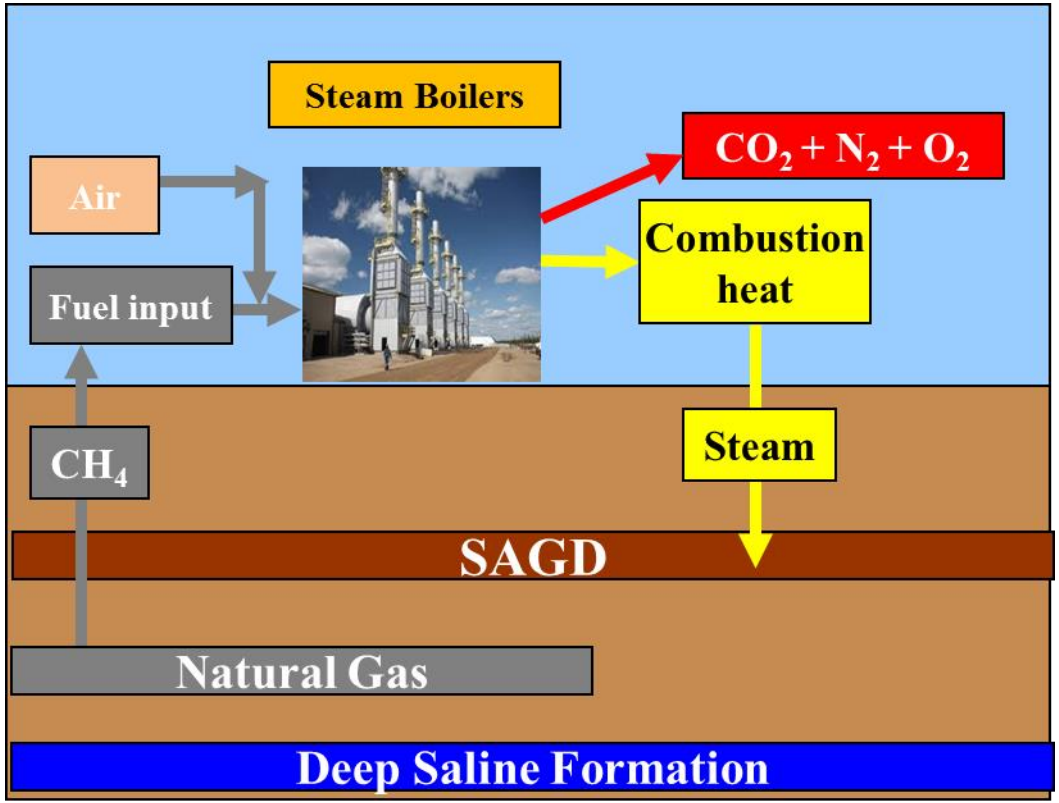
1. Introduction to CESAR and CAESR-Tech
2. SAGD with Conventional Cogeneration per CESAR Study
3. Advanced Cogeneration Technologies
    1. Molten Carbonate Fuel Cells
    2. Solid Oxide Fuel Cells
4. CASER-Tech SOFC improvements
5. Conclusions and Next Steps

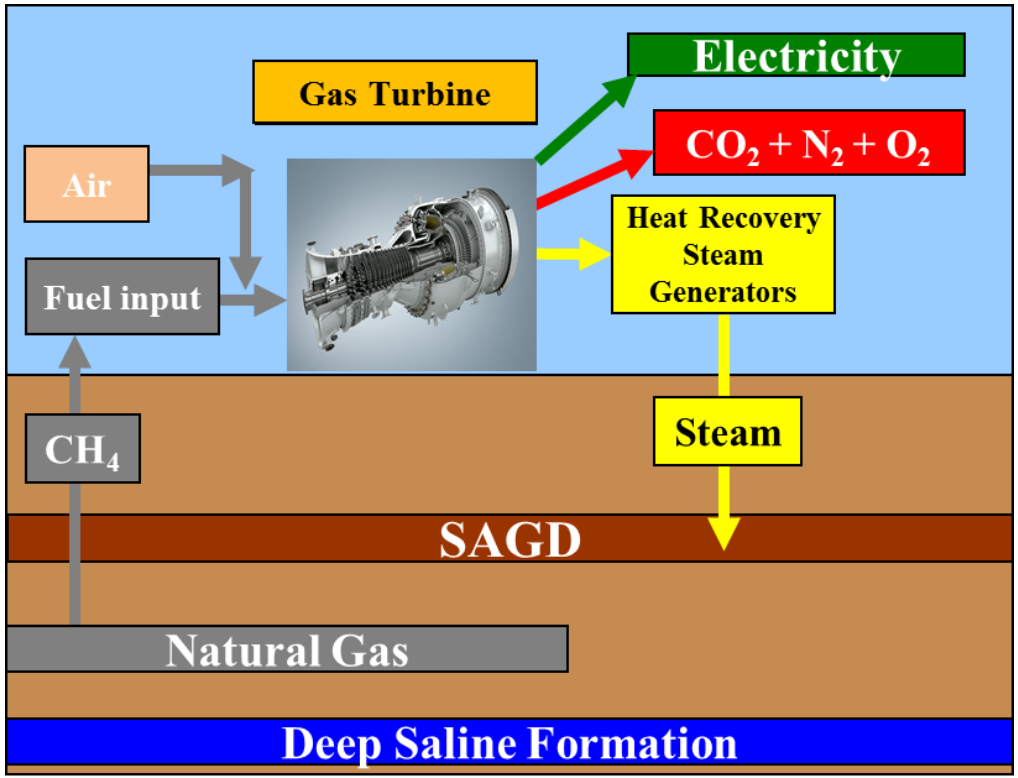
CESAR (Canada Energy Systems Analysis Research) is an initiative that was started at the University of Calgary in 2013 to understand and inform energy systems change in Canada. By building data resources and visualization tools, analyzing past and present energy systems and modeling energy futures, CESAR researchers work to inform policy and investment decisions regarding the transformation of Canada's energy systems towards sustainability. http://www.cesarnet.ca/

CAESR-Tech is a University of Calgary research center for research, training and innovation in next generation electrochemical energy storage/ conversion technologies. Our Mission is to develop advanced electrochemical technologies to achieve significantly lower or zero GHG emissions in the utilization of fuel resources in close collaboration with the energy/environment sector in Canada. http://www.ucalgary.ca/caesr/

Conventional SAGD

- Deploys OTSG to make steam and imports electricity from AB Grid
- Emission intensity @ 75 kg CO_2 per bbl is 3X conventional crude
- High intensity undermines public support for continued development
- AB Bill 25 limits total oil sands annual GHG emissions to 100 Mt
- Encourages cogeneration to reduce emission intensity





Conventional SAGD Cogen

- Conventional Cogen deploys GT to produce electricity and HRSG to make steam, as compared with conventional OTSG and power import
- CESAR extensively modeled multiple cases of deploying Cogen in a typical 33 kBPD SAGD project at SOR of 2 to 4
- In all cases, Cogen improves SAGD energy efficiency & reduces emission intensity

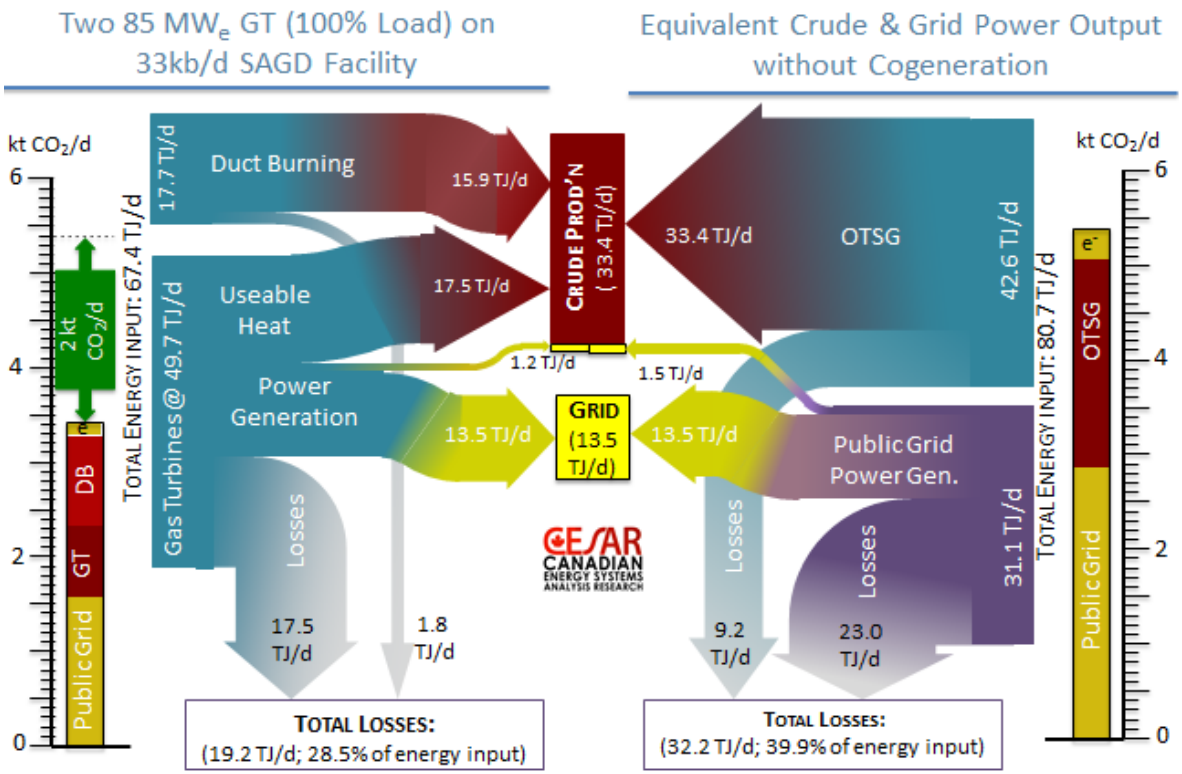
http://www.cesarnet.ca/sites/default/files/CESAR-Scenarios-SAGD-Cogeneration-Reducing-Carbon-Footprint-Oil%20Sands-Grid.pdf

CESAR SAGD Cogeneration Evaluation Cases

Case Studies	SAGD Heat	SAGD Power	Power to Grid
1. Base Case	OTSG	From Grid	No
2. One Cogen unit* @ 100% load factor	~50% OTSG ~50% Cogeneration	From SAGD Cogen	Yes
3. Two Cogen units* @ 100% load factor	Cogeneration		
4. Two Cogen units* @ 60% load factor (space for renewable backup)			

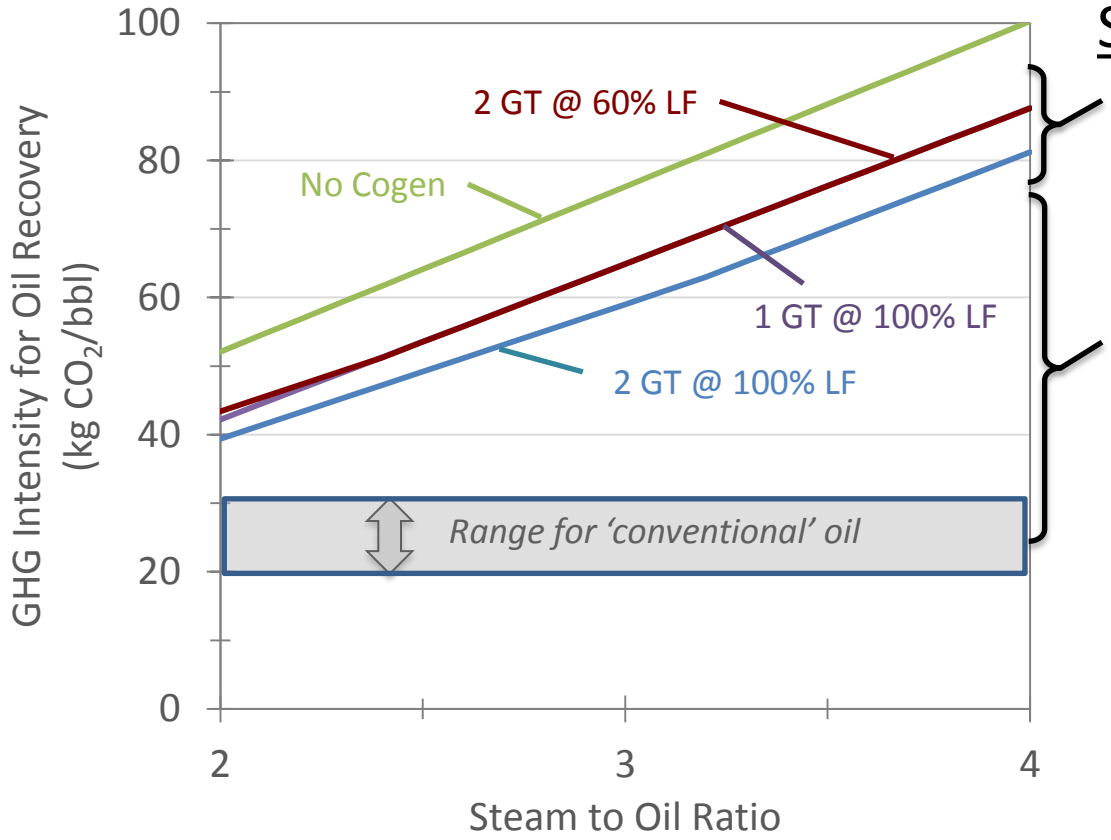
* *A cogen unit consists of an 85 MW_e gas turbine (GT), coupled to a heat recovery steam generator (HRSG) that can receive additional fuel (duct burning, DB), or addition fuel plus combustion air (forced air duct burning, FA-DB).*

A Systems Level Perspective



Sankey Comparison

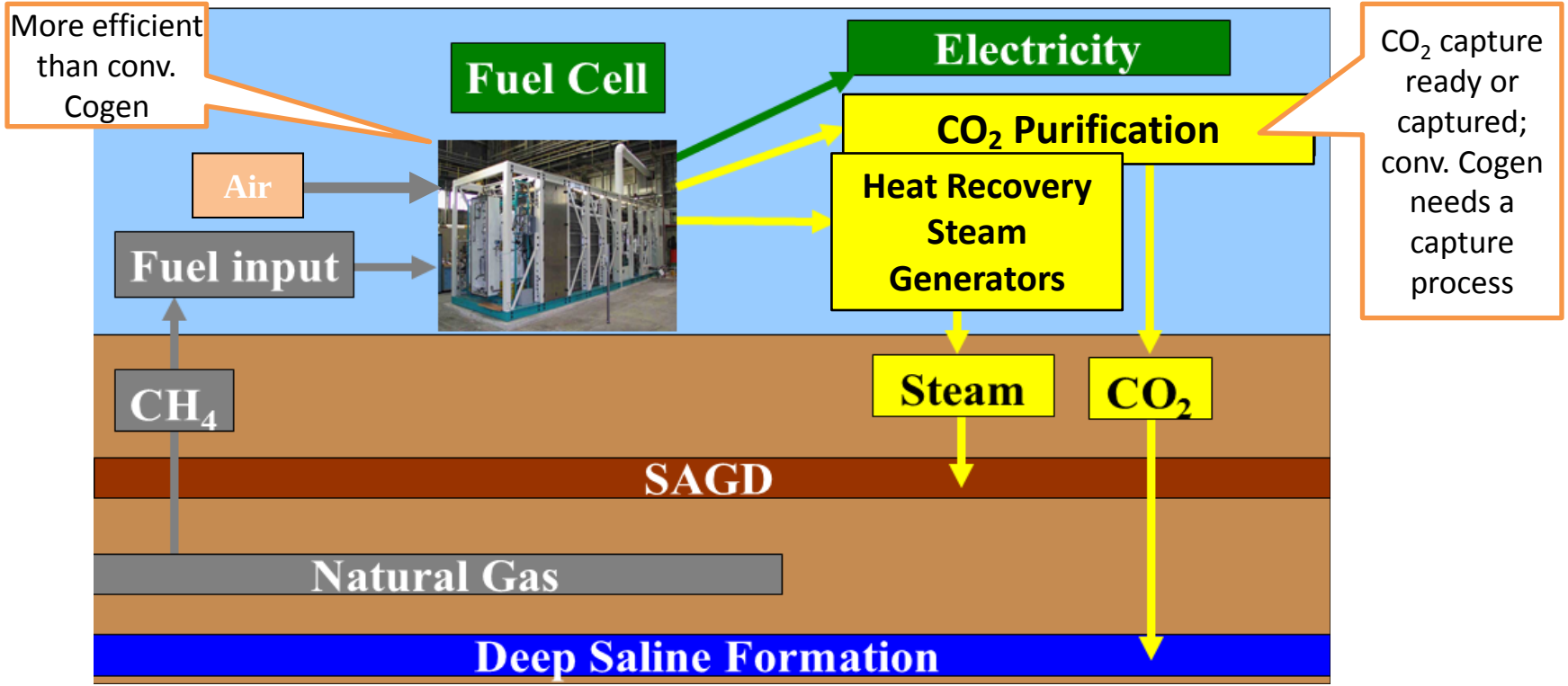
- Cogen thermal efficiency is 71.5%, 20% higher
- H/P = 2.3
- Exports 152 MW of low GHG intensity power (deemed 390 kg/MWh) vis-à-vis Grid intensity of 790 kg/MWh (2015)
- SAGD emission intensity reduced to 60 kg/bbl at SOR of 3, 25% reduction



SAGD Intensity with Cogen

- All Cogen Cases have lower GHG emissions per barrel than the base (no Cogen) case
- These emissions are still much higher than those associated with conventional oil
- Deploying two 85 MW running at 60% Load Factor could provide backup to renewables when ramping up to 100% LF
- Cogen is a transitional step to more advanced technologies

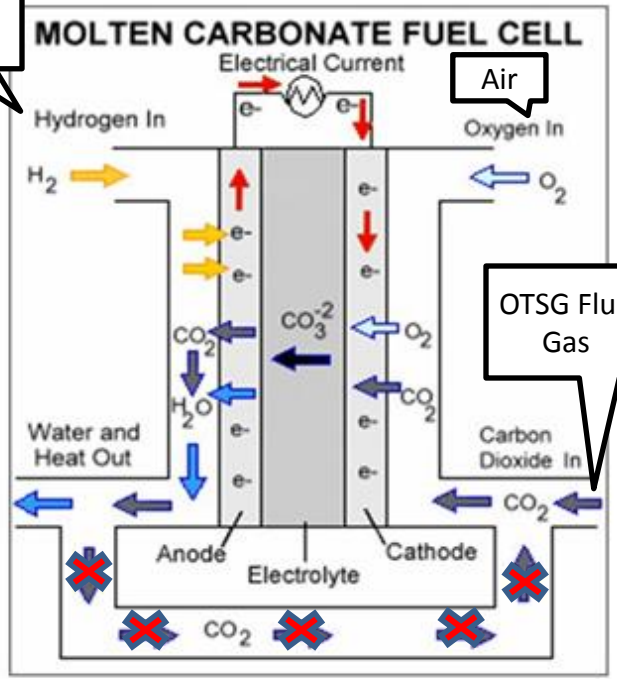
Fuel Cells are Advanced Cogen Technologies for SAGD



- Fuel cells could replace conventional Cogen of GT + HRSG
- Advanced electrochemical technologies suited for SAGD:
  - Molten carbonate fuel cells (MCFC)
  - Solid oxide fuel cells (SOFC)
- MCFCs concentrate CO_2 from steam boilers at lower avoidance cost vis-à-vis conventional PCC with amine, while exporting a modest amount of power, **and** *CO_2 must be disposed of*
- SOFCs produce steam and export power, and produced CO_2 is capture ready, i.e., CO_2 produced at high concentration, *either* emitted, *or* purified to EOR or storage specifications *later*

CH_4 is internally reformed

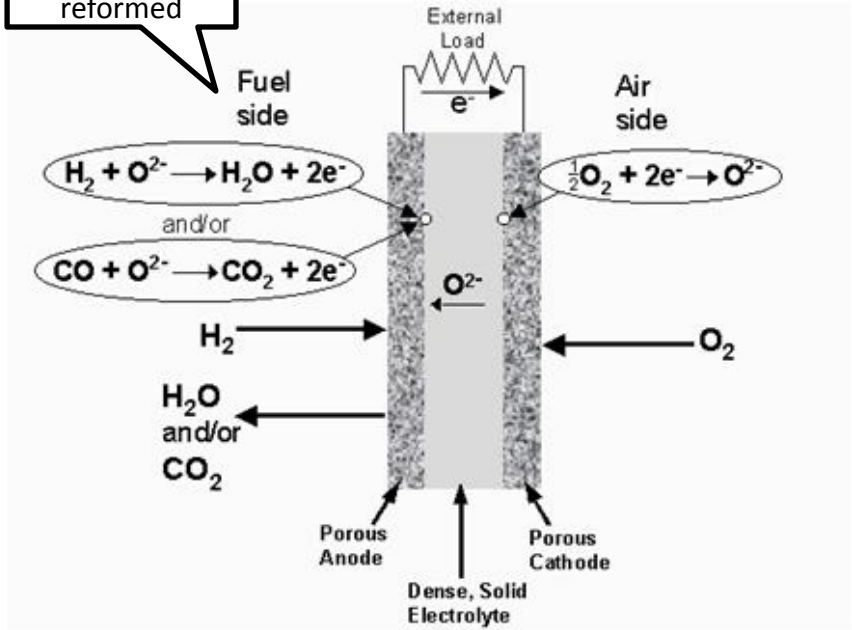
MCFCs



Molten carbonate electrolyte (< 650 °C)

CH_4 could be pre-reformed or internally reformed

SOFCs

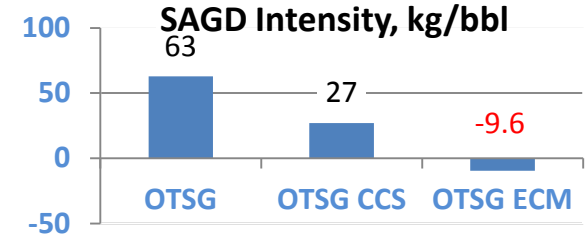


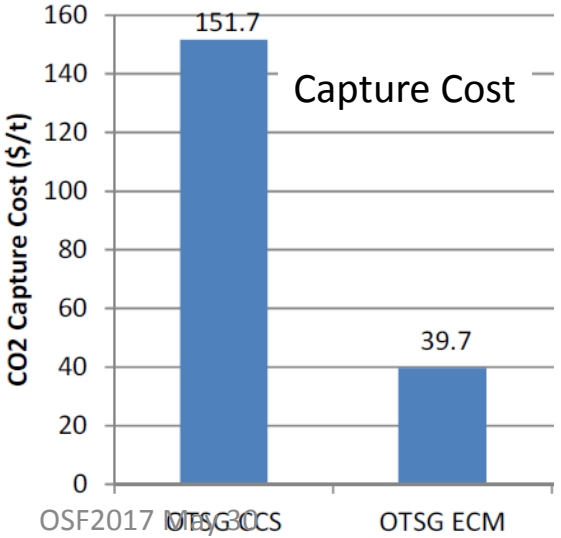
Ceramic metal oxide electrolyte (500-1000 °C)

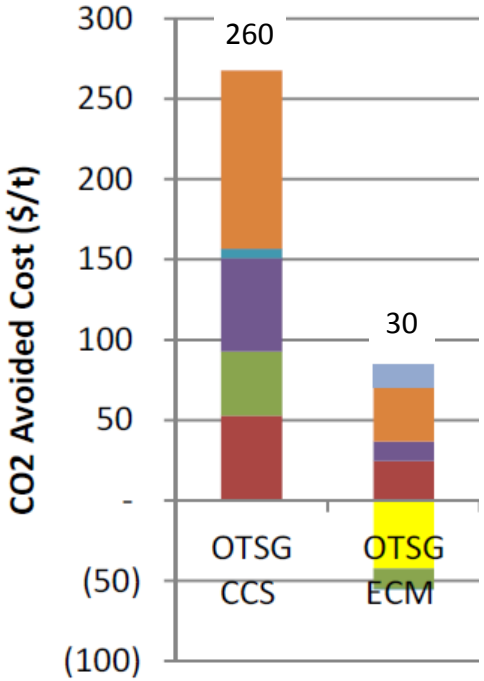
- AIEES and 5 oil sands producers in 2013 jointly funded a study to evaluate deploying these 2 types of fuel cells in SAGD (2013 Study)
- Base Case – conventional 33 kBPD SAGD at SOR of 3 using OTSG and importing power
- Install 76 MW MCFC, remove CO_2 from OTSG for storage, export modest amount of power (48 MW/33 kBPD), and compared with conventional SAGD with post combustion CCS using amine
- Install 1,100 MW SOFC, export prolific amount of power (960 MW/33 kBPD), steam recovered from exhaust gases for SAGD (H/P = 0.4), and compared with SAGD conv. Cogen, with or w/o CCS

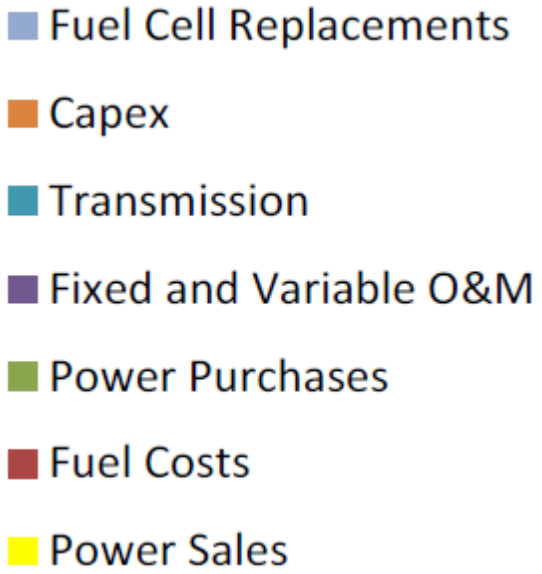
http://www.canadiancleanpowercoalition.com/files/4214/3018/3638/CCS29_-_ecm_evaluation_study_report-final_all.pdf

Key Study Results of MCFC with CCS



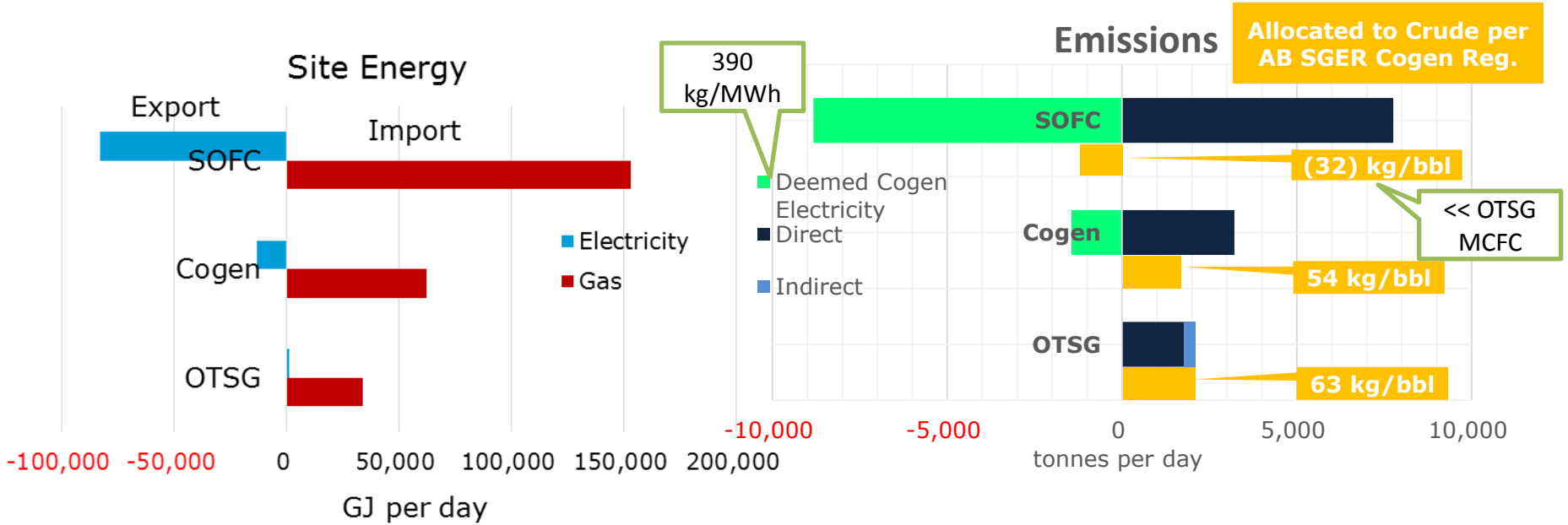






MCFC is aka ECM (electrochemical membrane) in the Study

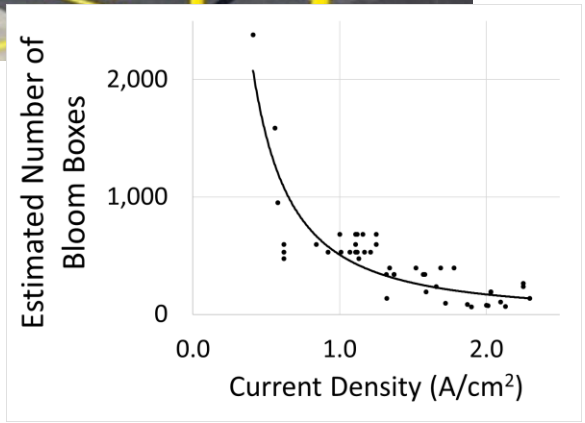
Key Study Results of SOFC without CCS

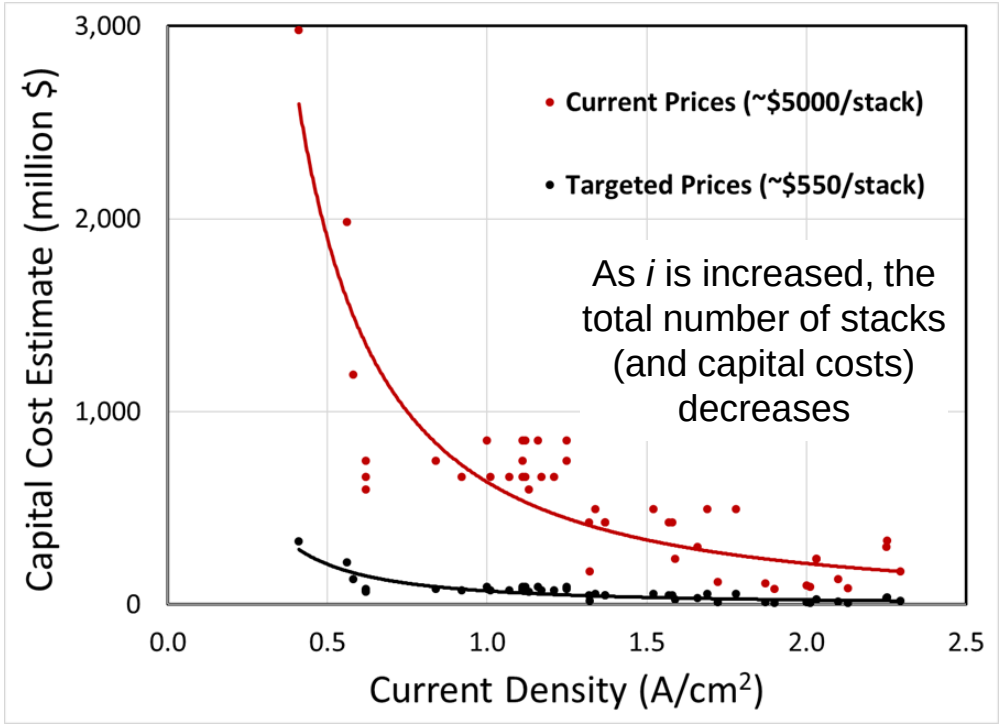


Note: 2014 Grid GHG intensity was 762 kg/MWh. All numbers shown above were extracted from the ECM Evaluation Report, Jacobs Consultancy, 2013. CESAR's Study has shown that OTSG's total GHG intensity is higher at 75 kg per barrel of which 10 kg per barrel is indirect.

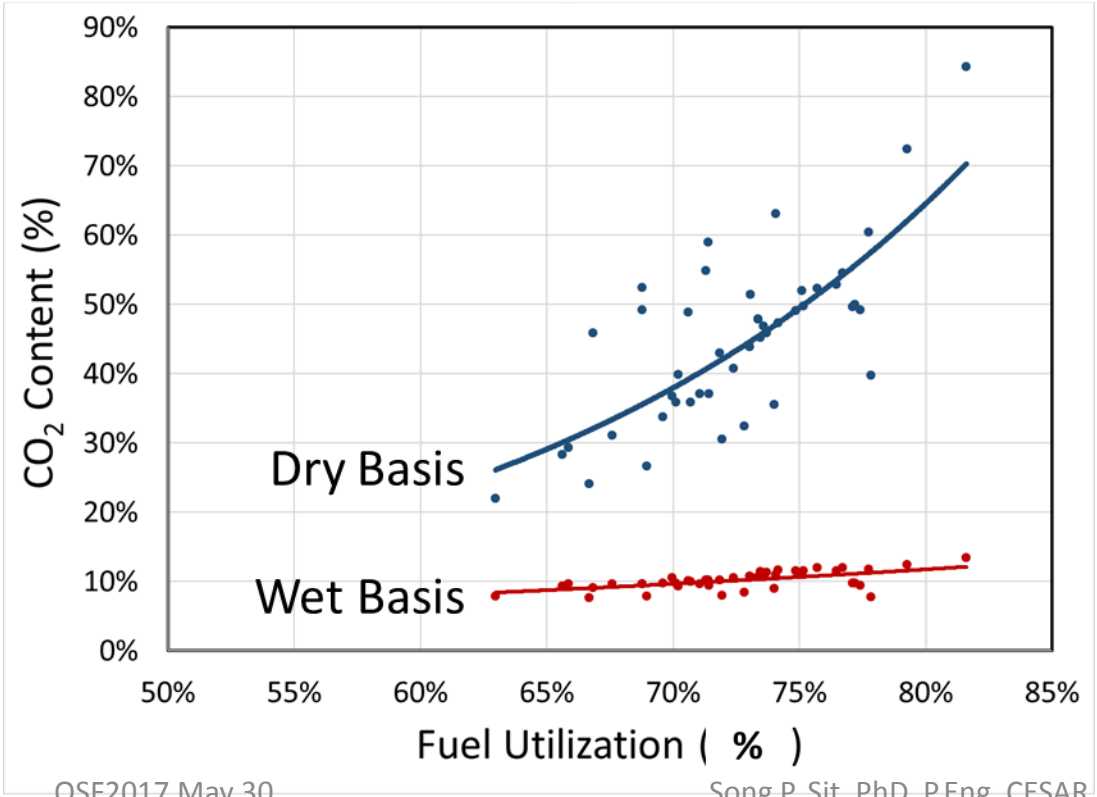
- The SOFC heat/power (H/P) ratio in the Study is 0.4, ~ 20% conv. Cogen and not attractive for SAGD
- CAESR-Tech carried out comprehensive simulations of implementing SOFC in SAGD
- Incorporated latest CAESR-Tech SOFC advancement and learnings in order to address the low H/P ratio
- Motivations are:
  - Increase SOFC's H/P ratio while keeping SOFC's high efficiency
  - Show potential SOFC capital cost reduction

Lower SOFC Capital Cost at Higher Current Density



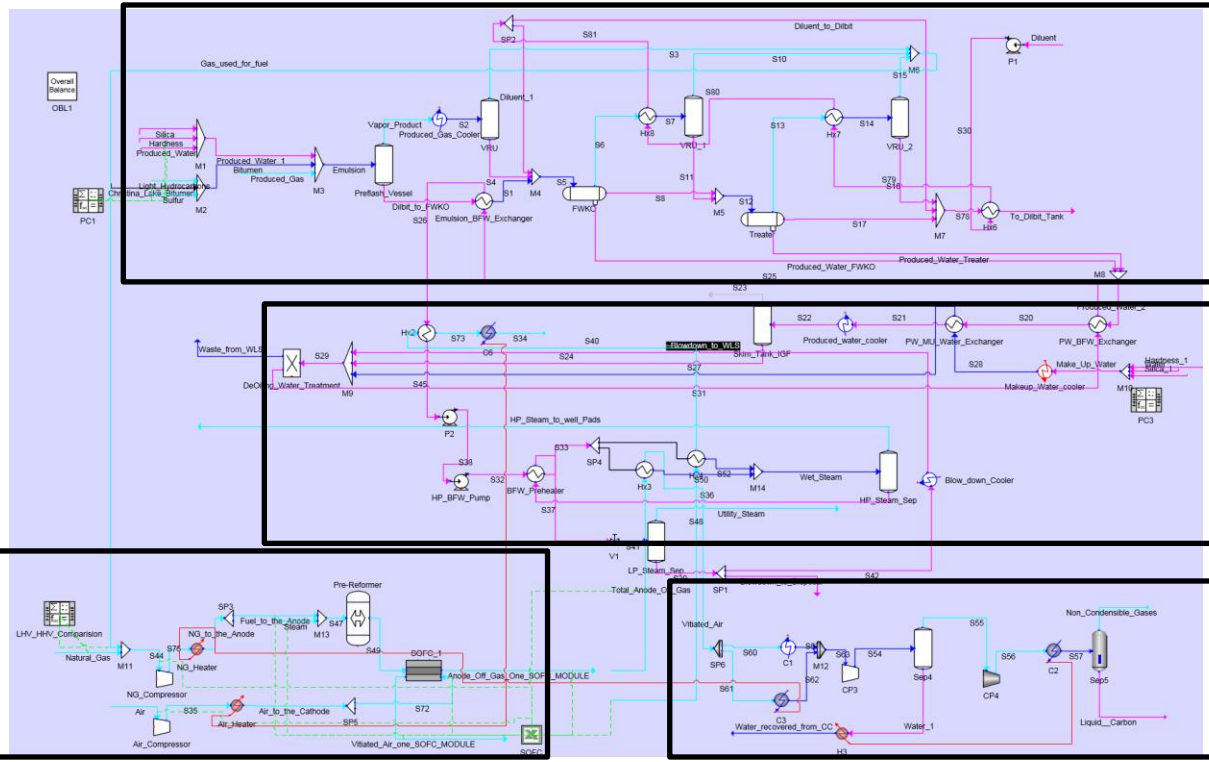


SOFC are CO_2 Capture Ready (no PCC with Amine)



- SOFC anode exhaust contains high CO_2 concentration, and low residual CH_4, CO & H_2
- Achieved at utilization efficiency > 80%
- Liquid CO_2 and residual fuels recoverable via purification
- CO_2 meets EOR spec
- Residual fuel recycled to achieve ~ 100% utilization

CAESR-Tech SAGD SOFC Process Simulation



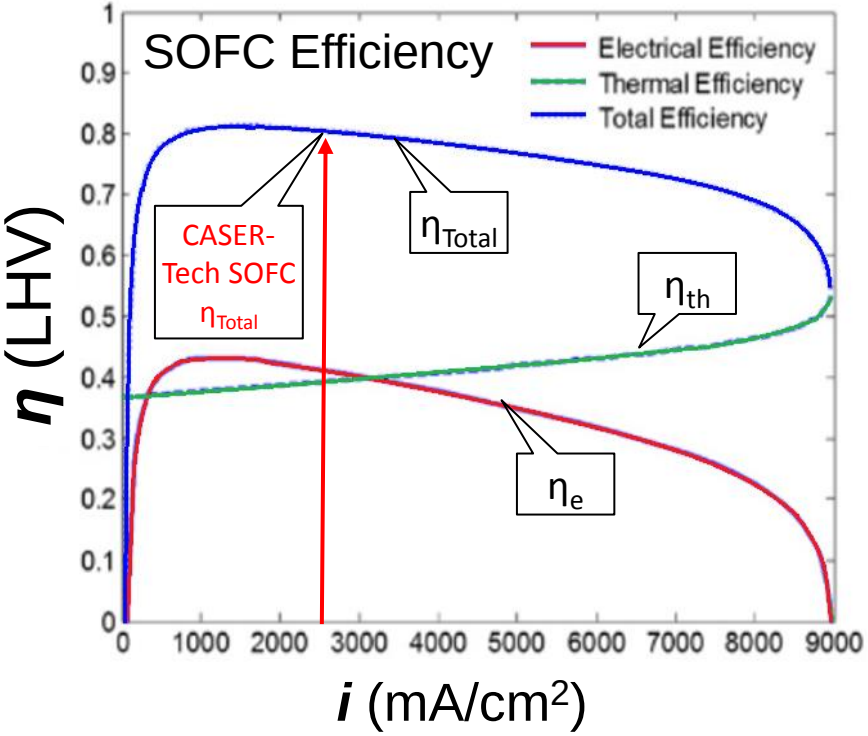
SAGD Oil & Water Treatments

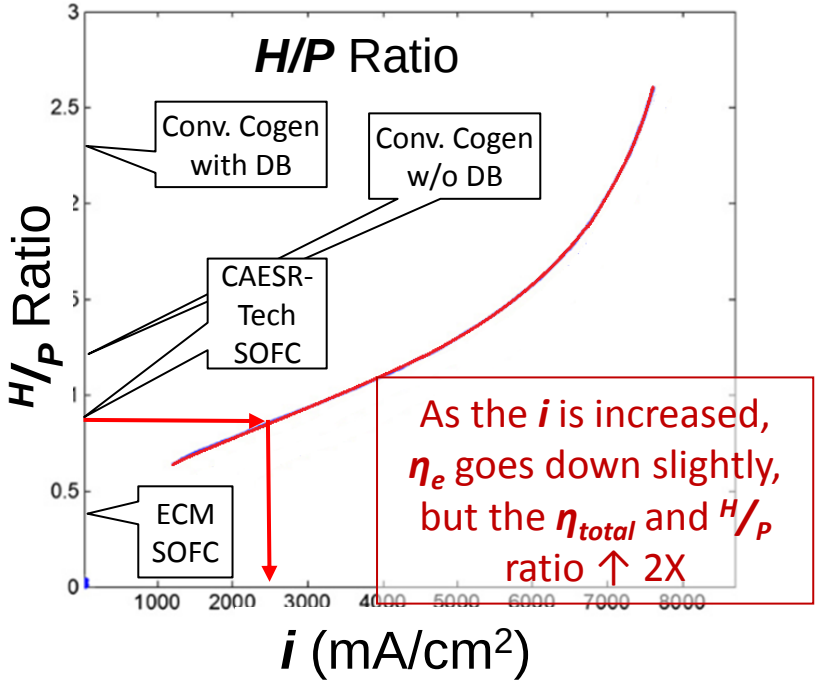
Heat Recovery Steam Generators

SOFC Systems

CO_2 Purification Systems

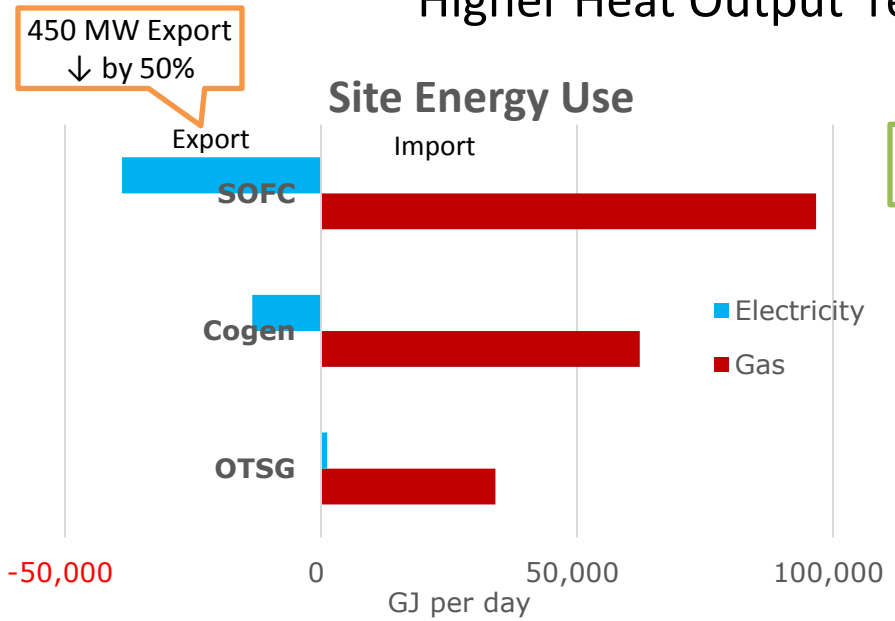
SOFC are Tunable to Output Different H/P ratio

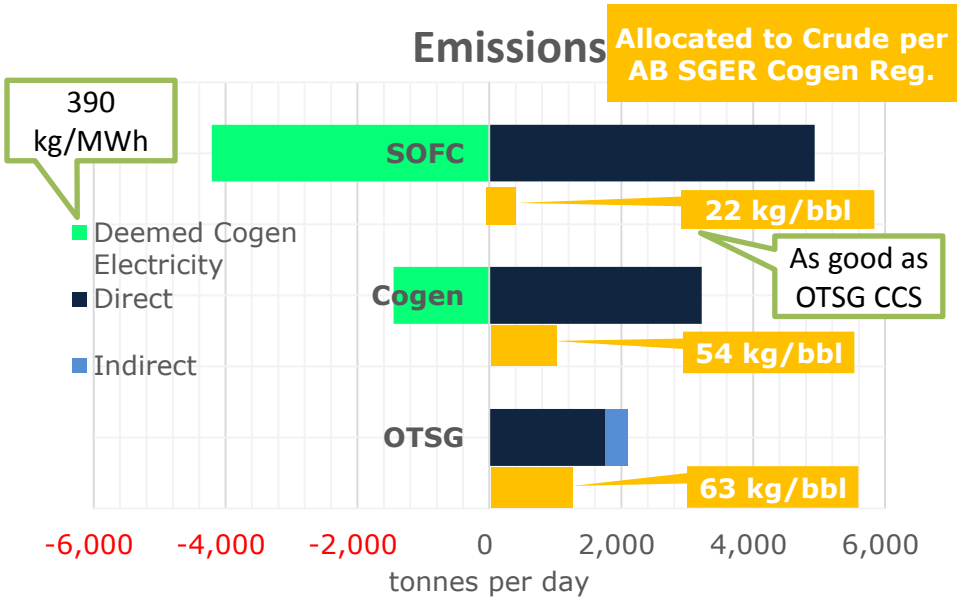




CAESR-Tech SAGD SOFC Results – H/P ↑ 0.8 w/o CCS

Higher Heat Output reduced Power Output





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Conclusions

- Cogeneration reduces SAGD emissions, allowing continued oil sands expansions under Bill 25's 100 Mt cap
- Conventional Cogen provides modest GHG reduction and a transition step to commercialize advanced Cogen technologies such as fuel cells
- MCFC and SOFC are both capable of Cogen and CCS
- SOFC is more attractive:
  - Highly efficient and CO_2 capture ready, not tied to PCC *per se,* as CO_2 purification to EOR or storage specs. can be retrofitted later
  - Operationally tunable, increasing H/P to 0.8, ~ 2 times 2013 Study
  - Potential to significantly reduce their capital costs

SOFC Next Steps

- Optimize H/P tuning for new SAGD production technologies, e.g., evaporators, SAP or ESEIEH, to find the most suitable H/P and current density (i) at the best fuel utilization (η_{Total}) for each
- Validate the optimization in collaboration with SOFC vendors and oil sands producers
- Scale up SOFC for SAGD:
  - 5 to10 kW pilot
  - Scale up in MW demo

Acknowledgements

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SOFC Study

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