



Idaho National Laboratory

Integration of High Temperature Gas Reactors with In Situ Oil Shale Retorting

**Eric P. Robertson, Michael G. McKellar,
and Lee O. Nelson**

Idaho National Laboratory

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Outline of Presentation

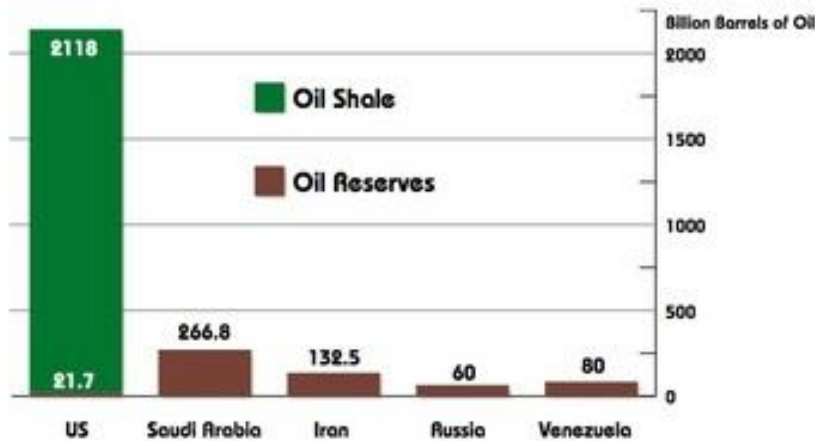
- **Background on in situ oil shale retorting**
- **Oil and gas production from oil shale**
- **Modeling the integration of HTGR heat to in situ oil shale retorting**
 - **Base case and HTGR-integrated case**
- **Mass and energy balance of both cases**
- **CO₂ emissions**
- **Monte Carlo simulation**
- **Heat transportation distance**
- **Summary, conclusions, and recommendations**

Why Oil Shale?

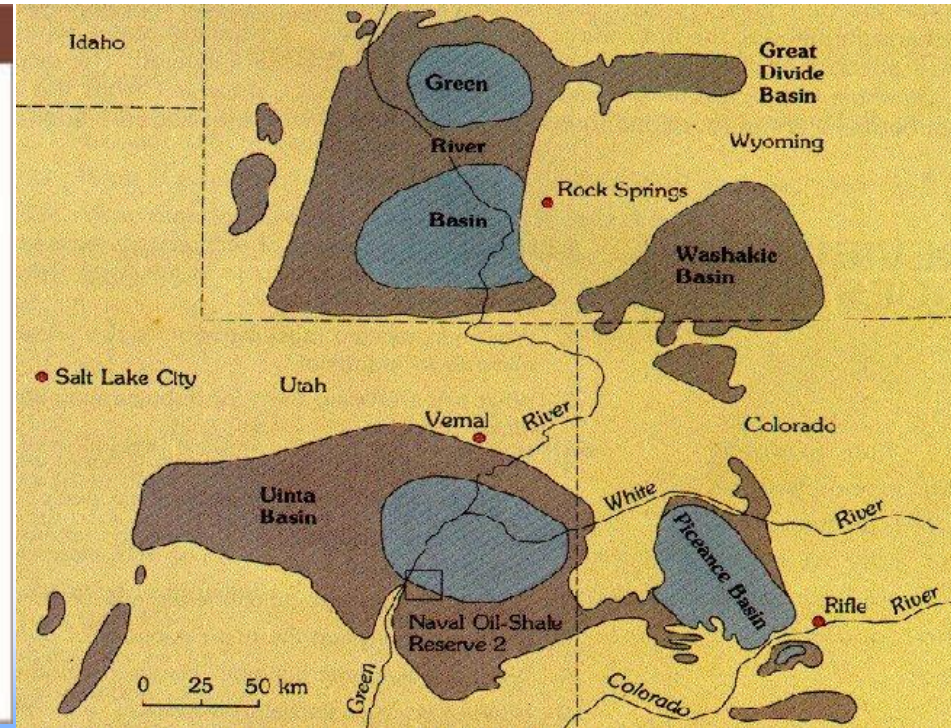
- Need for liquid transportation fuel will continue
- Oil shale resource is huge
- Green River Formation in Colorado, Utah, and Wyoming is over 3 trillion barrels

PETROLEUM

Potential US Oil Shale Energy
v. Foreign Oil Reserves



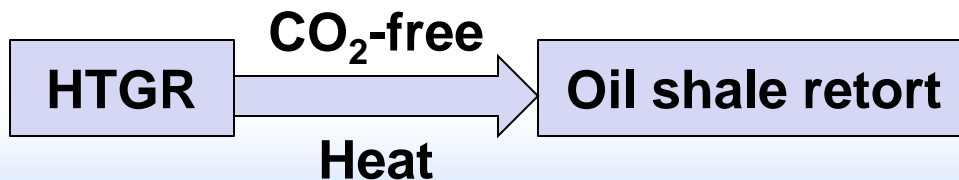
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Source: International Energy Annual 2005



What Is Oil Shale?

Why are WE Talking About It?

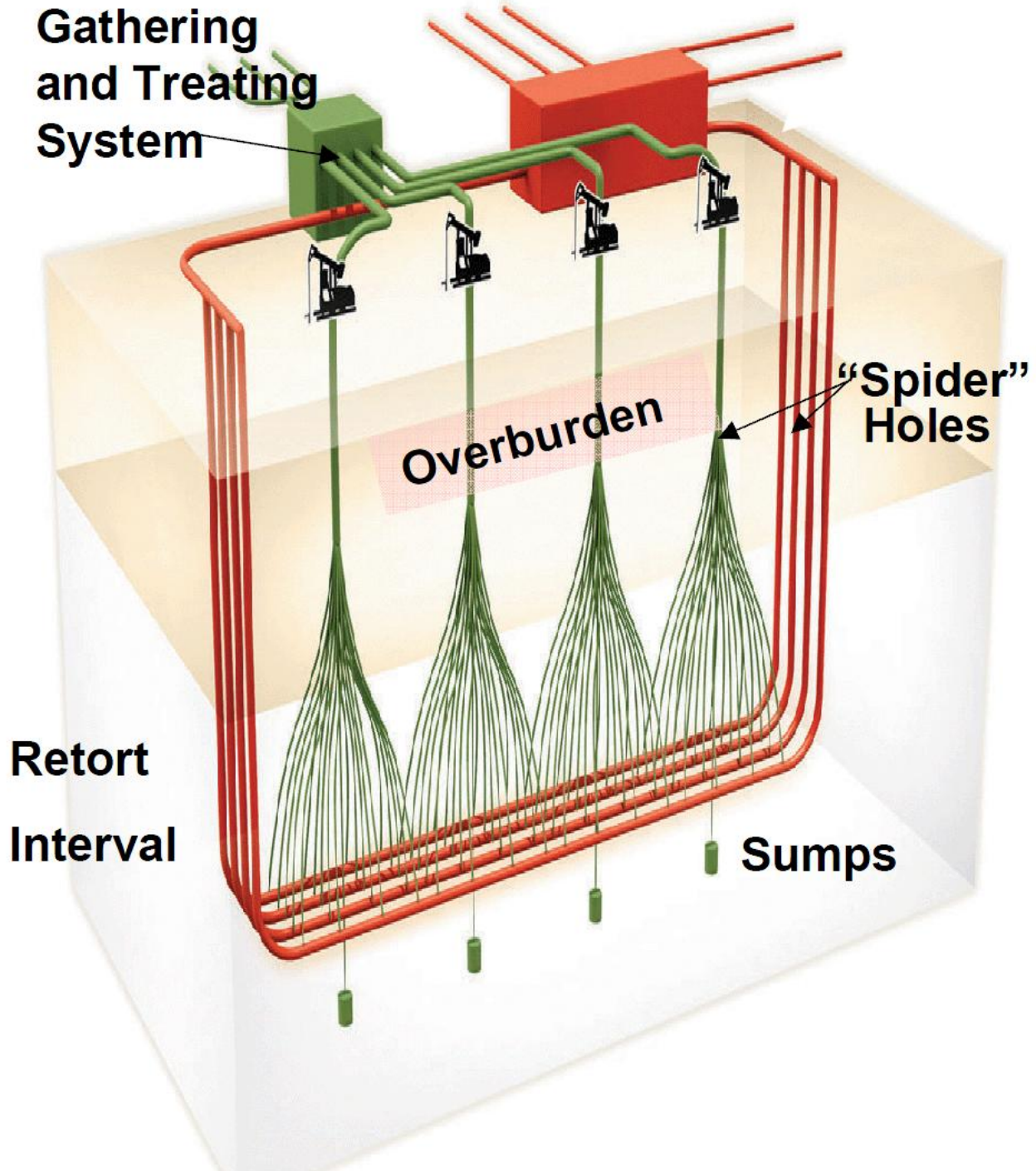
- Not the same as gas shale
- Kerogen is immature oil
 - Not enough heat or pressure to be converted to conventional oil or gas
- Oil shale is kerogen rich
- Retorting
 - Pyrolysis
 - kerogen to oil, gas, and char
 - Heat-intensive process



Timing of In Situ Oil Shale and HTGR Deployment

- **No current commercial-scale in situ oil shale production**
- **Field-scale RD&D projects currently operating**
- **A large-scale, commercial in situ oil shale industry**
 - **emerge within the next 10 to 15 years**
- **Development and deployment of a commercial HTGR**
 - **require 10 to 15 years**
- **Study of integrating an HTGR with an in situ oil operation is timely**

Gathering and Treating System



Overburden

"Spider" Holes

Retort Interval

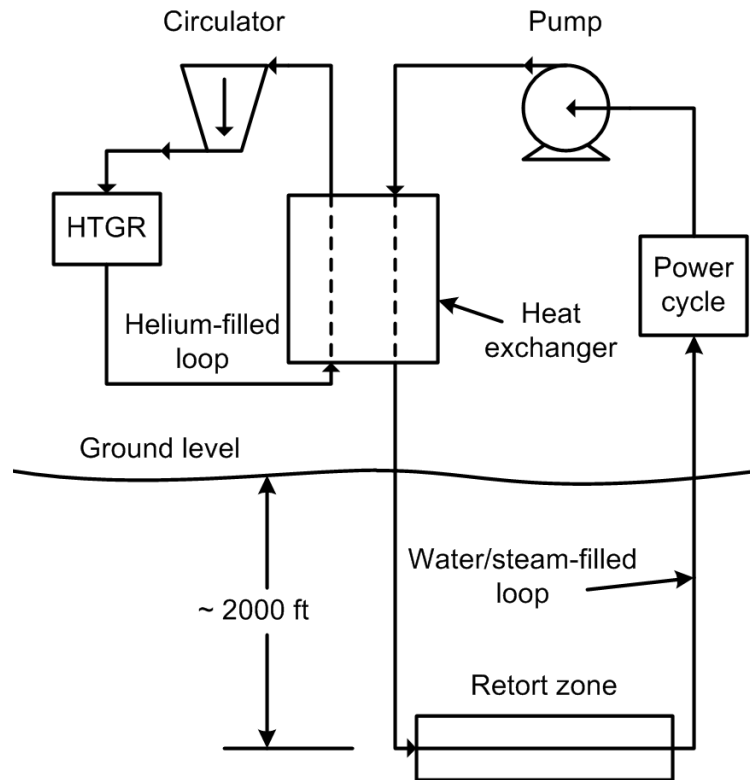
Sumps



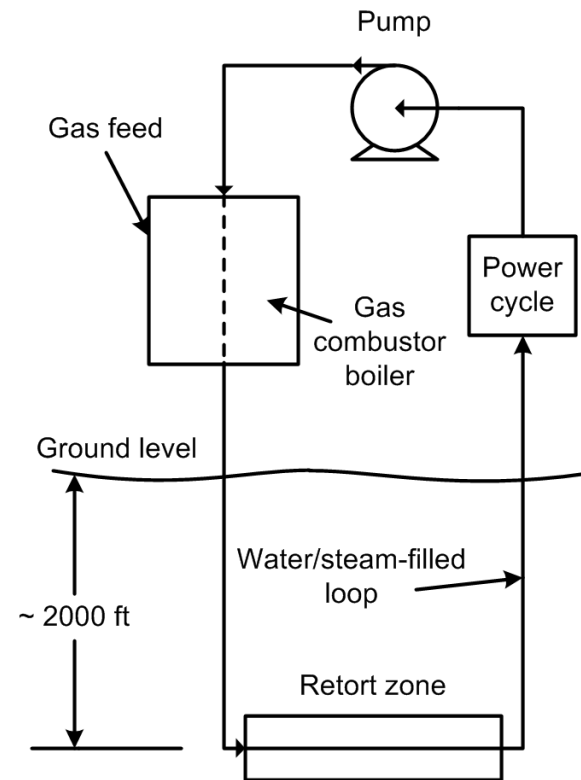
Modeling Integration of HTGR to In Situ Oil Shale

- **Two cases considered (50,000 bbl/day oil output)**
 - **Base Case:**
 - Retort heat transfer fluid is high-pressure steam
 - Heat provided by gas-fired burner
 - **HTGR-Integrated Case:**
 - Retort heat transfer fluid is high-pressure steam
 - Heat provided by heat transfer loop connected to HTGR
- **Mass and energy flows**

Modeling Integration of HTGR to In Situ Oil Shale



(A) HTGR-integrated case



(B) Base case

Material Balance

- Site specific
- Based on AMSO's RD&D site in western Colorado

Pyrolysis product	per ton of raw oil shale				
	gal/ton	scf/ton	MJ/ton	kg/ton	\$ \$100/bbl \$6/MMBTU
Oil	20.0	—	2830	62.6	47.62
Gas	—	652	1210	23.6	6.90
Char	—	—	1090	34.5	—
Total	—	—	5130	120.7	54.52

**A ton of raw oil shale is about 14.6 cu. ft
(cube with sides 30 inches in length)**

Energy Balance

- **Energy output**

	Base case	HTGR case
Energy Output		
Oil total, MW	3431	3431
Gas total, MW	1482	1482
Electricity total, MW	114	114
Total output, MW	5027	5027

- **Energy input**

Energy Input		
Gas into burner/boiler, MW	1122	—
HTGR, MW	—	1007
Steam pump, MW	3	3
Helium circulator, MW	—	30
Processing facilities, MW	6	6
Total input, MW	1131	1047

- **Energy ROI**

(return on investment)

EROI, MW_{out}/MW_{in}	4.44	4.80
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Carbon Dioxide Emissions

- **CO₂ comes from two sources**
 - **Mineral decomposition**
 - **Gas combustion**

Case	Total CO ₂ Emitted	
	m ³ /D	tonne/D
Base Case	3,203,000	5,982
HTGR-Integrated Case	259,000	483

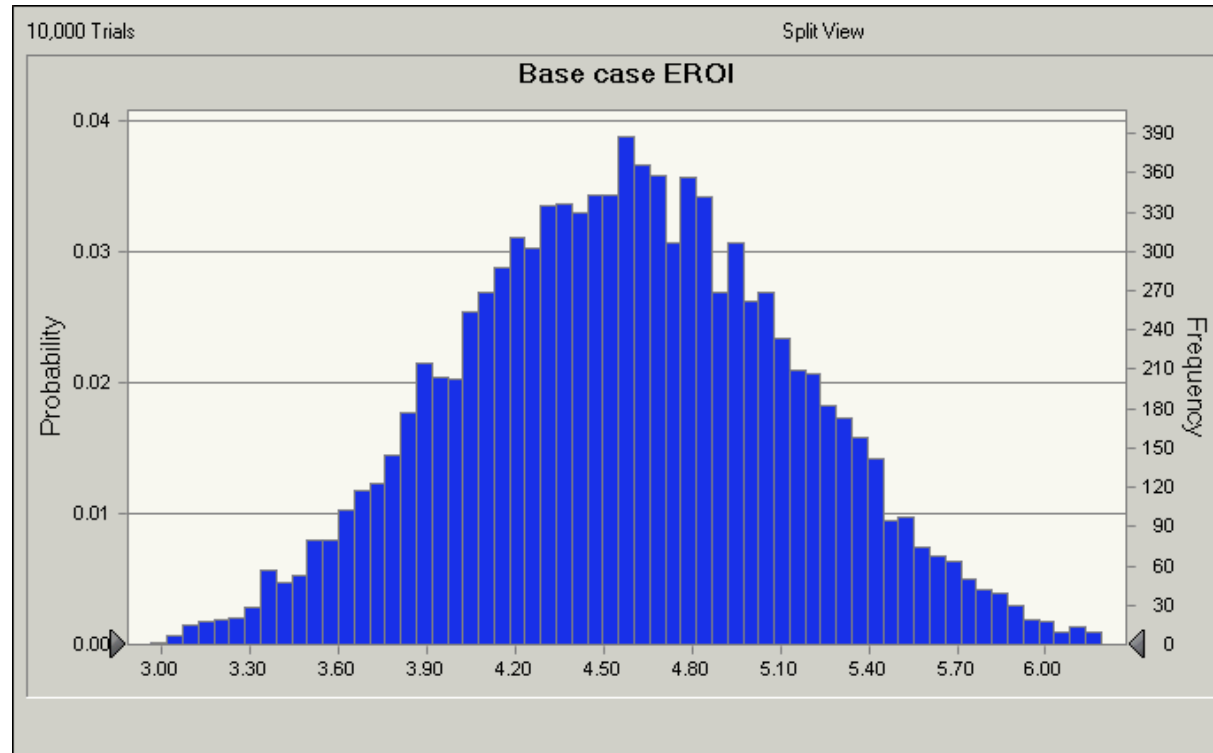
Probabilistic Results

- **Base Case**

- Mean EROI =
4.58 +/- 0.57

- **HTGR Case**

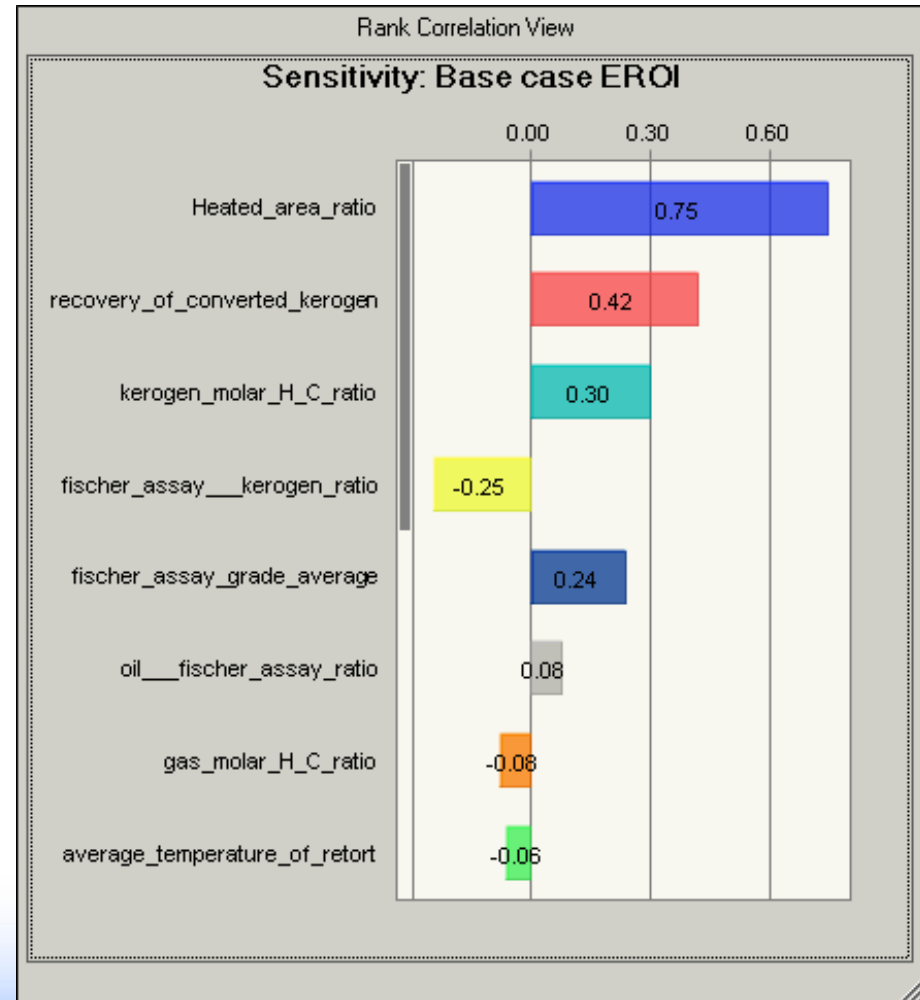
- Mean EROI =
4.90 +/- 0.58



Sensitivity Analysis

Critical input variables for both cases were:

1. Heat transfer rate through oil shale
2. Recovered fraction of converted kerogen
3. Elemental composition of kerogen
4. Kerogen content of oil shale



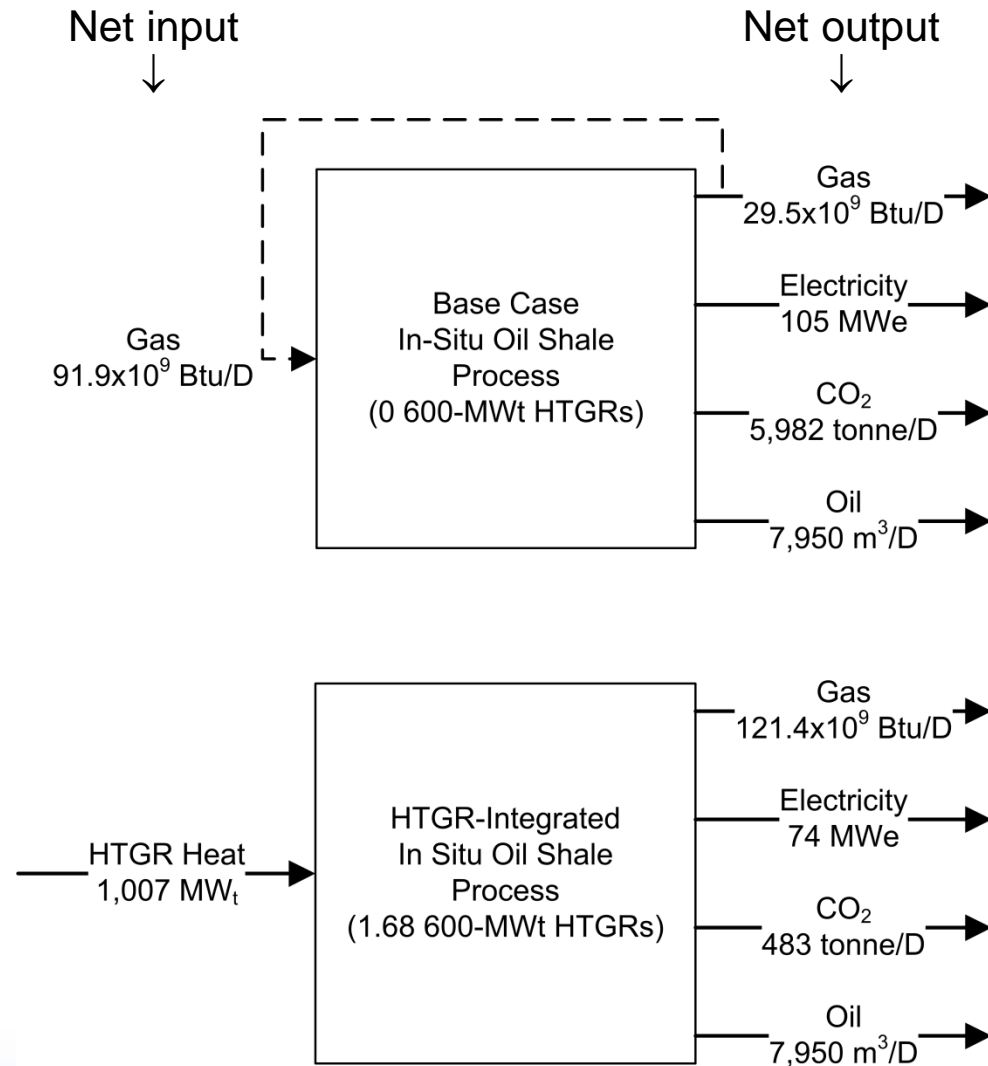
Distance for Heat Transportation

- **Site-specific assumptions**
 - 230-ft thick retort zone
 - 50,000 bbl/day output
 - Etc.

Years of oil production	Total barrels of produced oil	Acres of development	Maximum heat transportation distance, miles
30	594 million bbl	2060	1.0
60	1.14 trillion bbl	4120	1.4

Summary

- **Net gas sold**
 - HTGR-case sells 4 times as much gas
 - 75% of the gas in base case is recycled
- **12 times more CO₂ is produced in base case**
- **Less heat input with HTGR case**
- **EROI of HTGR case is greater than base case**
- **Transportation of heat not expected to be problematic**
- **HTGR integration is not only technically feasible, but promising**



Recommendations for future work

- **Economic analysis**
 - As basis for case comparison
- **Heat transfer rate through retort zone**
 - Identified as most critical input variable
 - Reduce the uncertainty by narrowing variable range
- **Energy for CO₂ capture, compression, and storage**
 - Incorporate into energy balance
 - Needed for clearer comparison between cases

Thank You

Contact Information:

Eric Robertson

email: eric.robertson@inl.gov

phone: 208-526-7456