Material Resource Considerations for Ex Situ Carbon Sequestration

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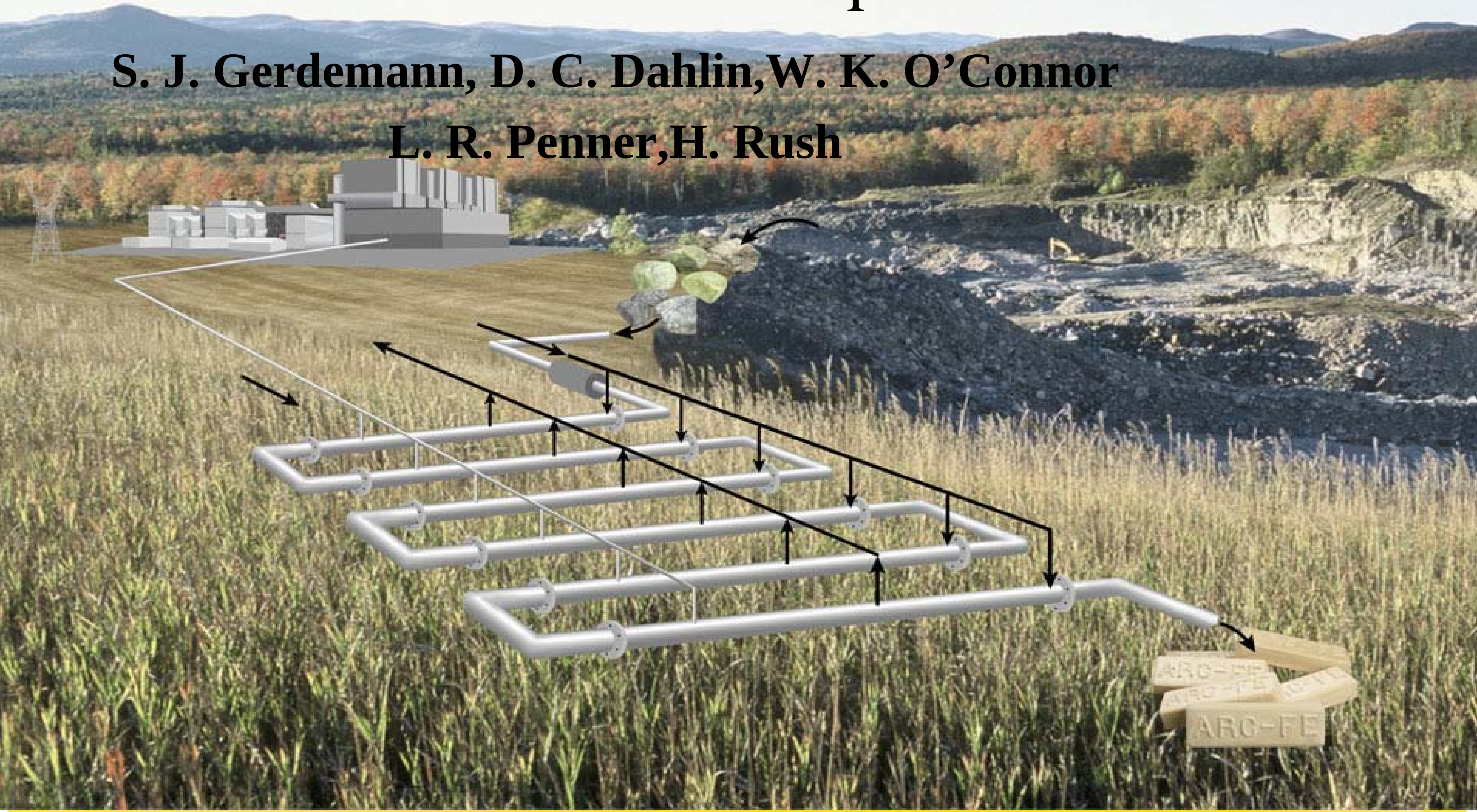

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Office of Fossil Energy - U.S. Department of Energy

Solutions that make the Nation's energy systems safe, efficient and secure

Scope of Problem

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- 22,000 Mt/yr anthropomorphic CO_2 emitted worldwide
- 1990 U.S. Emissions of CO_2 = ~ 5,000 Mt/yr
- 2003 U.S. Emissions of CO_2 = ~ 5,780 Mt/yr
- A 1-Gigawatt Coal-fired Power Plant Emits ~ 8.8 Mt CO_2/yr

Ex-Situ Processes

- Advantages
  - Low leak rate
  - Vast quantities of reactants available
  - Potential resource recovery
- Disadvantages
  - Cost
  - Environmental impact

Minimum Requirements for an Ex Situ Process

- The mineral resource must be large enough to store a significant quantity of CO_2.
- The mineral resource must be near the CO_2 point source.
- The process products must be environmentally benign and stable.
- The use of energy for the process must be kept to a minimum.
- The economic impact of the process must be kept to a minimum.

$$R_{CO_2} = \frac{\text{Mass of Mineral}}{\text{Mass of } CO_2 \text{ Sequestered}}$$

R_{CO2} is a function only of mineral composition

Theoretical Reactions

Olivine — Serpentine — Magnesite

$$2Mg_2SiO_4 + CO_2(g) + 2H_2O \rightarrow Mg_3Si_2O_5(OH)_4 + MgCO_3$$

Olivine — Magnesite

$$Mg_2SiO_4 + 2CO_2(g) \rightarrow 2MgCO_3 + H_4SiO_4 \qquad R_{CO_2} = 1.6$$

Serpentine — Magnesite

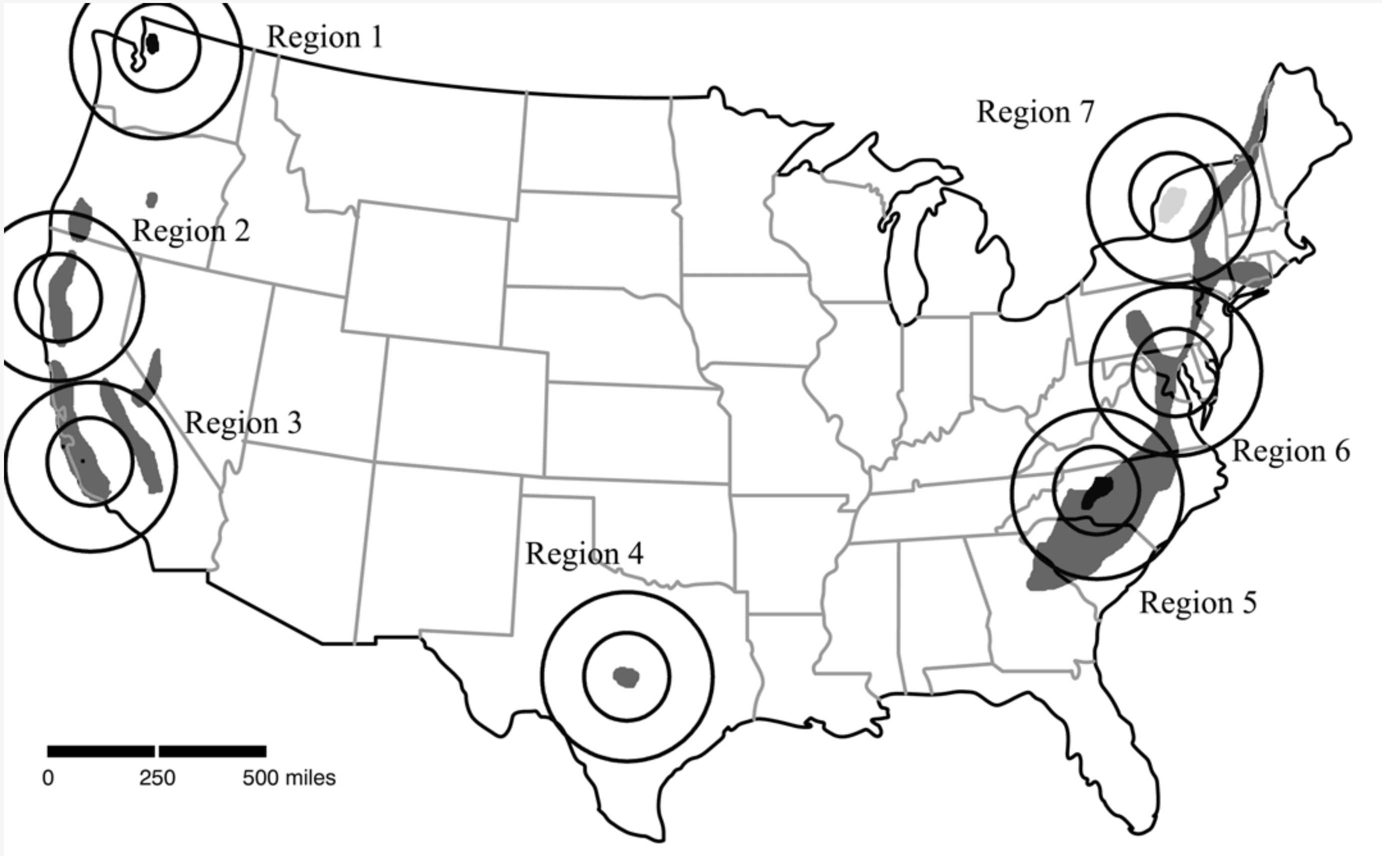
$$Mg_3Si_2O_5(OH)_4 + 3CO_2(g) + 2H_2O \rightarrow 3MgCO_3 + 2H_4SiO_4 \qquad R_{CO_2} = 2.1$$

Wollastonite — Calcite

$$CaSiO_3 + CO_2(g) \rightarrow CaCO_3 + H_4SiO_4 \qquad R_{CO_2} = 2.6$$

Fayalite — Siderite

$$Fe_2SiO_3 + 2CO_2(g) \rightarrow 2FeCO_3 + H_4SiO_4 \qquad R_{CO_2} = 2.1$$


Region 1
Region 2
Region 3
Region 4
Region 5
Region 6
Region 7
0
250
500 miles

Ultramafic Resources

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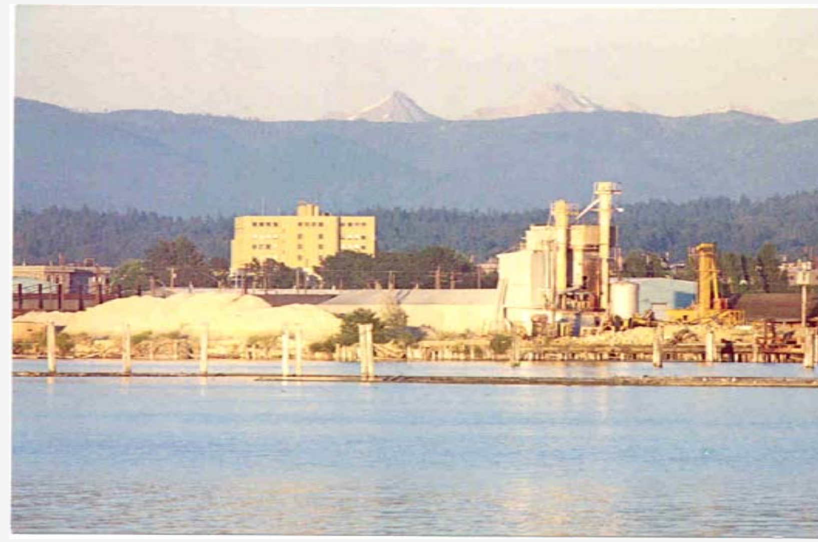
Region	Mining District/Deposit	Mineral	Size of Resource	Mineral Composition				R_{CO2}
				Mg	Ca	Fe^{2+}	LOI	
1	Twin Sisters, WA	Olivine dunite	1.8 Gt	31	0.11	6.0	0.39	1.6
2	Trinity-Siskyou Mtn, CA- OR	Serpentine lizardite	Large	24	0.31	2.4	15	2.2
3	Coast Range Central CA	Serpentine Lizardite	Large	20	0.64	2.0	13	2.7
4	Llano Uplift, TX	Serpentine lizardite	>1 Gt	25	0.07	0.30	15	2.2
5	Asheville, NC	Olivine	200 Mt	29	0.13	6.7	0.39	1.7
6	State Line, MD-PA	Serpentine antigorite	Large	26	0.02	2.6	14	2.0
7	Willsboro, NY	Wollastonite	14 Mt	0.27	33	.50	3.2	2.7

Region 1: Olivine Ore and Twin Sisters Mine

Mg_2SiO_4



Bellingham, WA
Processing Plant

Twin Sisters
Mine

Region	Mining District/Deposit	Mineral	Annual Production Mt	R_{CO2}	Radius Miles	CO_2 Mt	CO_2 Sequestered	
							Mt	Regional Total %
1	Twins Sisters WA	Olivine	0.21	1.8	100 100-200	13 5	0.12	0.9 0.65
5	Asheville NC	Olivine	----	1.8	100 100-200	54 133	--- ---	
7	Willsboro NY	Wollastonite	0.15	2.8	100 100-200	11 65	.05	0.49 0.07

Region 7: Wollastonite Ore and Mine

$CaSiO_3$

Willsboro, NY Mining District

Wollastonite

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1	Twins Sisters WA	Olivine	0.21	1.8	100 100-200	13 5	0.12	0.9 0.65
5	Asheville NC	Olivine	----	1.8	100 100-200	54 133	--- ---	
7	**Willsboro NY**	**Wollastonite**	**0.15**	**2.8**	**100 100-200**	**11 65**	**.05**	**0.49 0.07**

Deposit is ~ 14 MT

Region 6: Antigorite Serpentine and Active Quarry

$Mg_3Si_2O_5(OH)_4$

State Line District, PA-MD

Serpentine

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Region	Mining District/Deposit	Mineral	R_{CO2}	Radius, Miles	CO_2 Mt	Ore Requirements Mt
2	Trinity-Siskiyou Mtn, CA-OR	Serpentine lizardite	2.5	100 100-200	10 ---	25 ---
3	Coast Range Southern CA	Serpentine lizardite	2.5	100 100-200	10 ---	25 ---
4	Llano Uplift TX	Serpentine lizardite	2.5	100 100-200	30 42	75 105
6	State Line MD-PA	Serpentine antigorite	2.1	100 100-200	106 125	222 263

Other Mineral Resources

- Coal fly ash
- Cement kiln dust
- Waste concrete
- Steel making slag
- Electric arc furnace dust
- Asbestos mining tails

Other Mineral Resources

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Composition of Coal

	Anthracite	Bituminous Pittsburgh #8	Subbituminous Wyoming	Lignite San Miguel, TX
As-received Heating value, BTU/lb	11890	12540	9190	2740
Fixed Carbon	83.7	74.0	70.3	18.4
Moisture	7.7	17.6	24.1	21.2
Ash	**10.5**	**9.1**	**5.7**	**68.8**
SiO_2	51.0	50.58	32.61	66.85
CaO	0.6	1.13	15.12	1.76
MgO	0.3	.62	4.26	0.42
R_{CO2}	**125.2**	**63.9**	**6.1**	**54.4**

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Cement Kiln Dust

- ~ 5 Mt/yr
- Assuming 85% CaO, $R_{CO2} = 1.5$
- Sequester 3.3 Mt CO_2
- Distance to source of CO_2?
- Alternate uses – soil liming

Waste Concrete

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- Unknown amount
- R_{CO2} higher than for cement kiln dust
- Transportation costs?
- Cost of size reduction
- Less reactive than kiln dust

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Steel Making Slag

- ~25 Mt/yr
- Generic composition
  - 35% SiO_2
  - 12.5% Al_2O_3
  - 42.5% CaO
  - 3% MgO
- $R_{CO2} = 2.7$
- Sequester ~ 9.3 Mt/yr CO_2
- Size reduction
- Transportation costs

Electric Arc Furnace Dust

- 0.65 Mt/yr
- Small size eliminates size reduction
- Contains metals that may cause problems
  – Zn, Cd, Pb

Other Mineral Resources

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Asbestos Mining Tails

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- Size of resource
  - ~ 5 – 8 Mt in California & Vermont
  - 40 Mt Baie, New Foundland
  - 25 Mt Cassiar, B. C.
  - 90 Mt Quebec
- R_{CO2} = ~2.2
- Carbonation will destroy asbestos molecule
- Material is already ground eliminating the cost of size reduction

Conclusions

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- There are enough ultramafic resources to sequester all the CO_2 produced by coal-fired powerplants in the U.S.
- Sequestering all the CO_2 would require a significant increase in the mining of ultramafic minerals.
- The increased mining will have an environmental cost.
- Some man made by product minerals could contribute to CO_2 sequestration although many of these resources are small.
- It may be possible in some cases to sequester CO_2 and eliminate hazardous waste in the same ex situ process.

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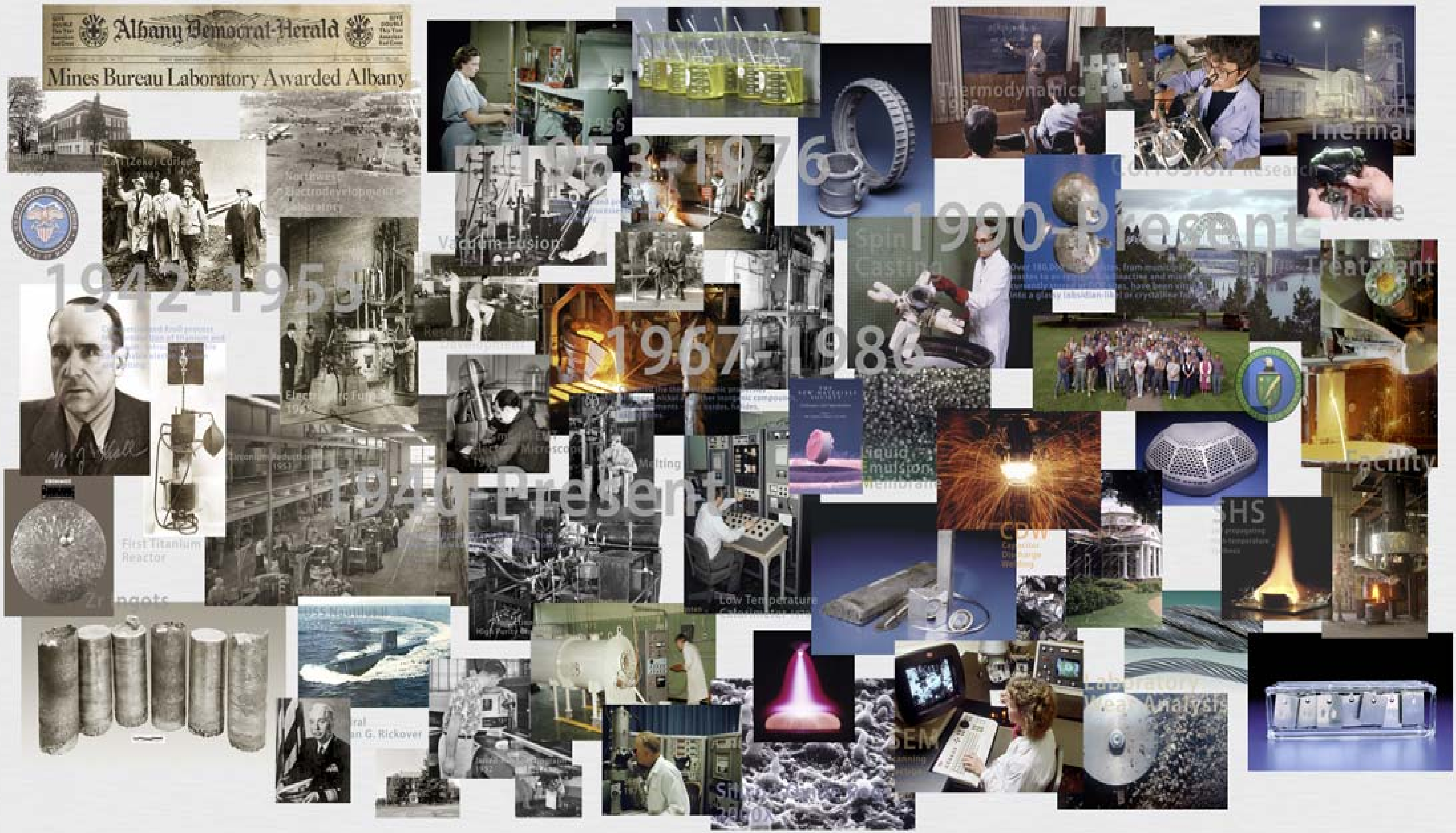

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Twin Sisters Olivine Mine