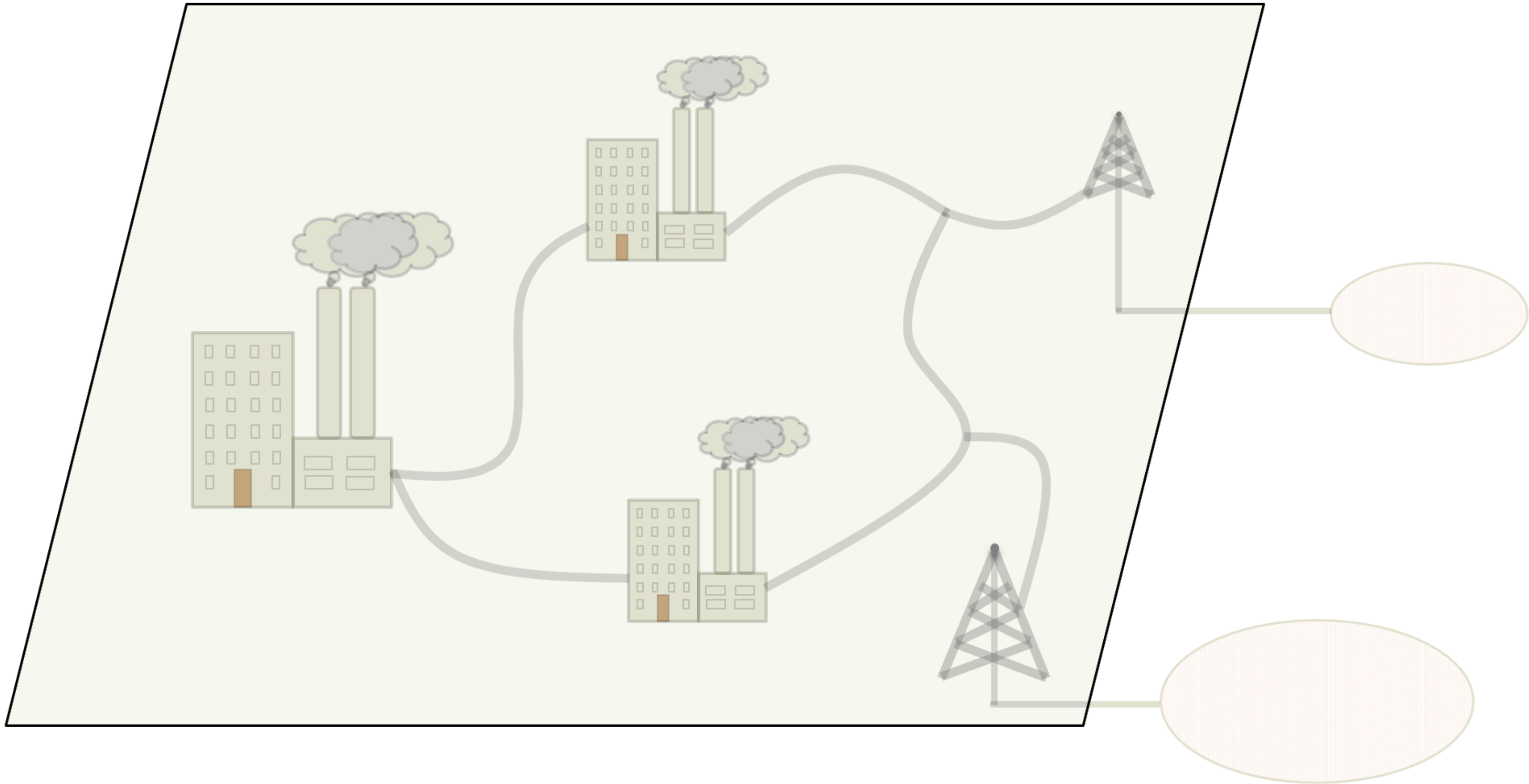
Planning Amongst Uncertainty:

Designing CCS Infrastructure Resilient to Capture, Transport, and Storage Uncertainty



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Montana State University

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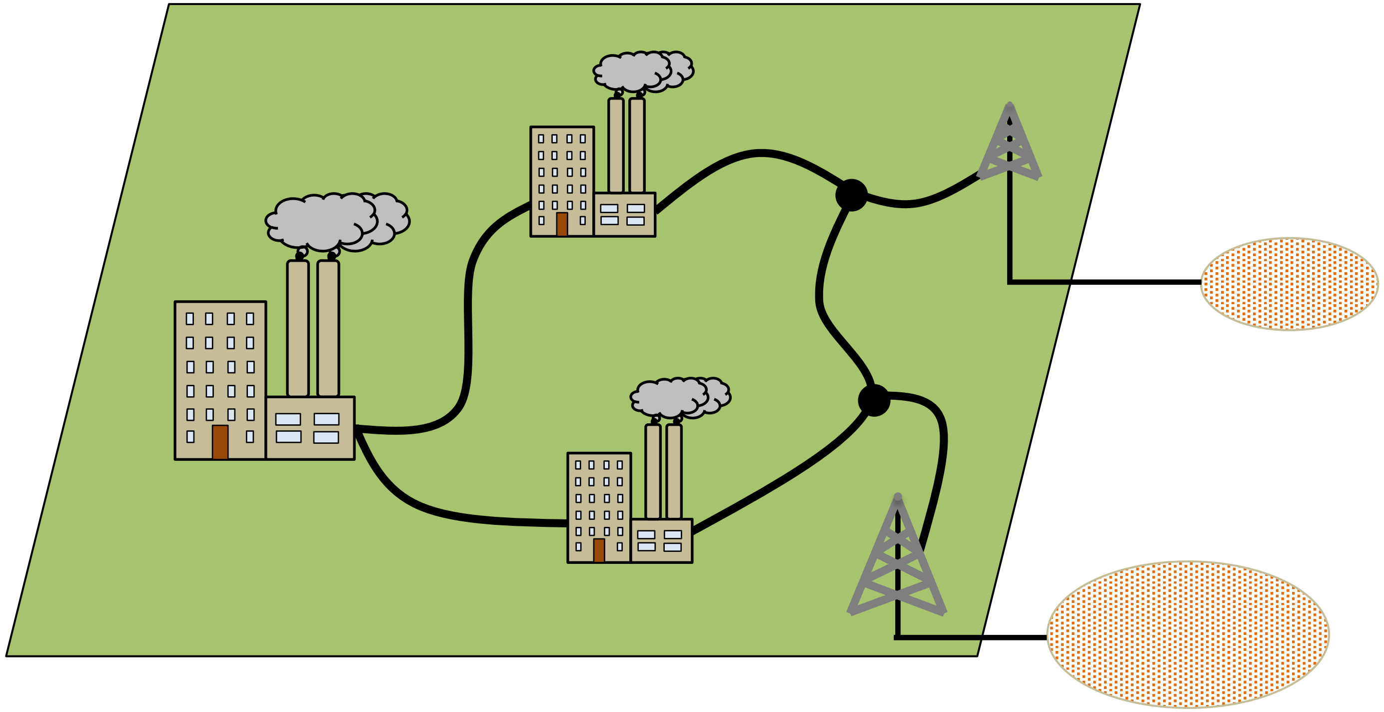
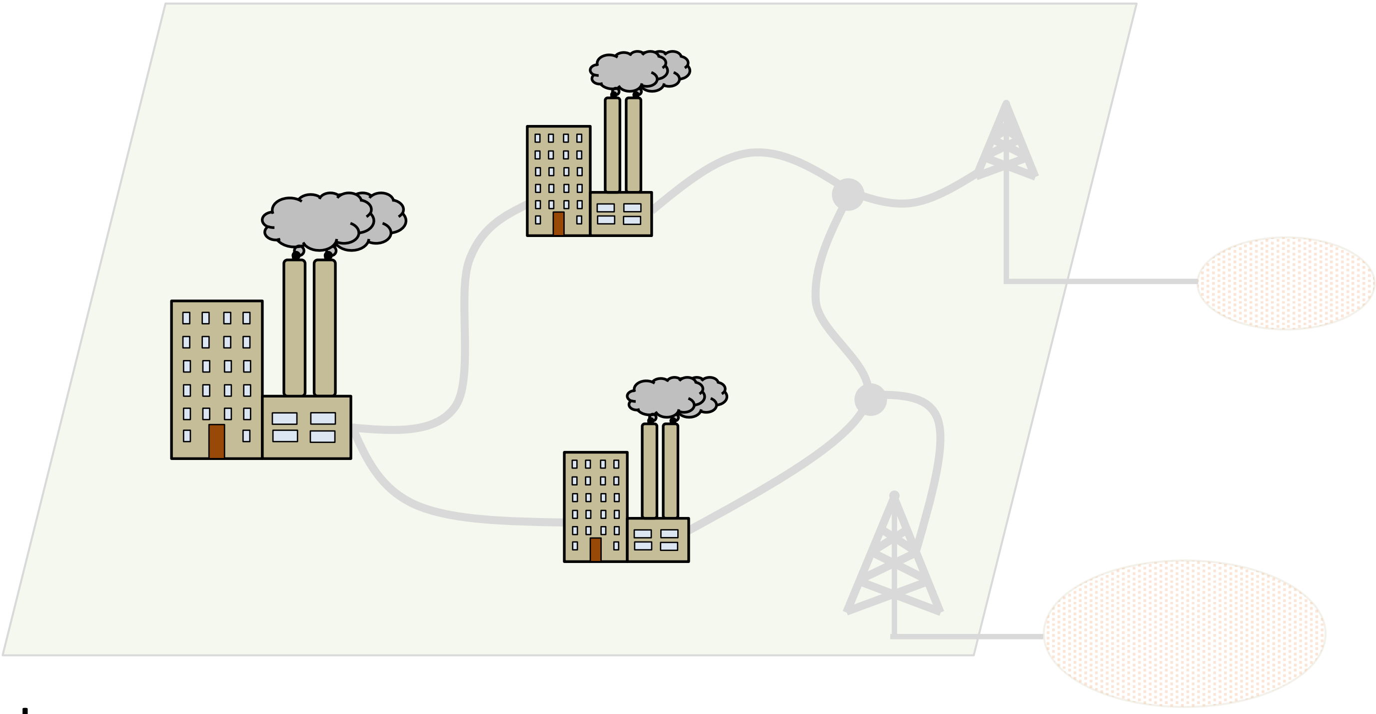
Designing CCS Infrastructure



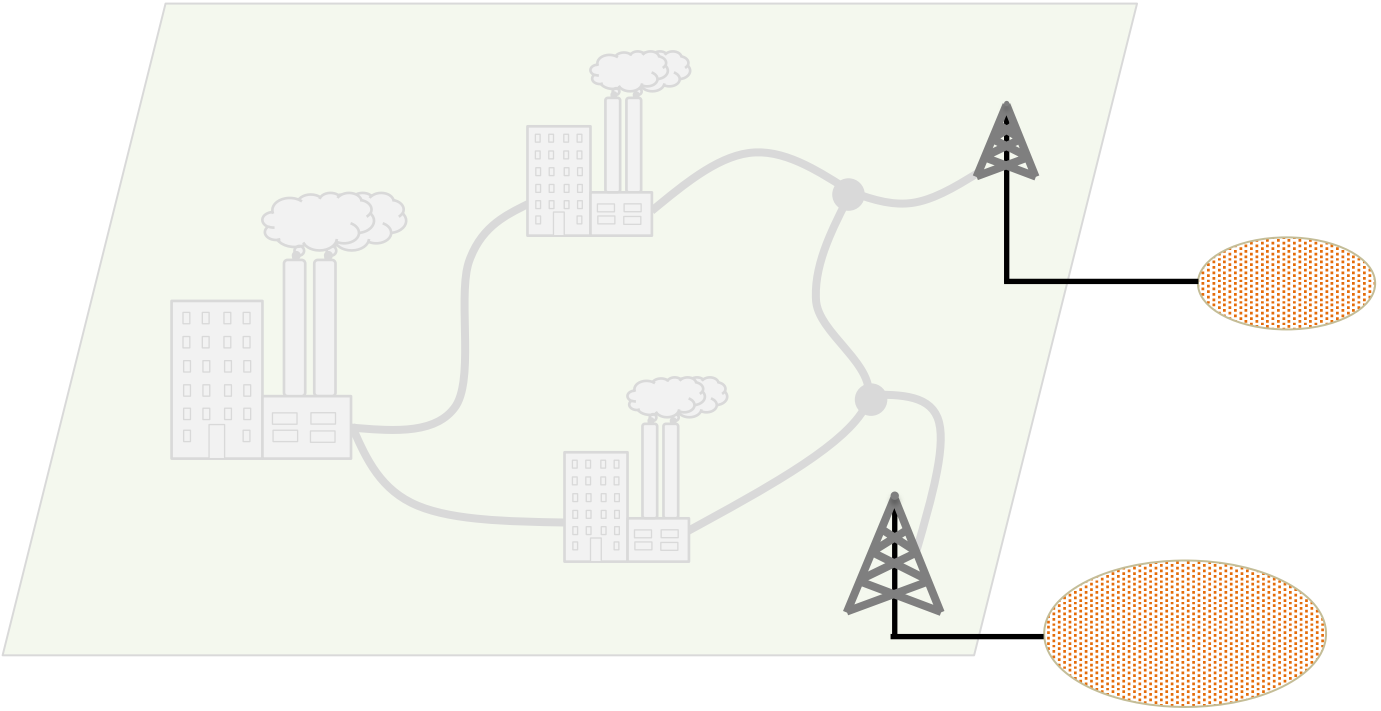
Designing CCS Infrastructure



Capture:

- Location
- Capture cost
- Capturable amount

Designing CCS Infrastructure

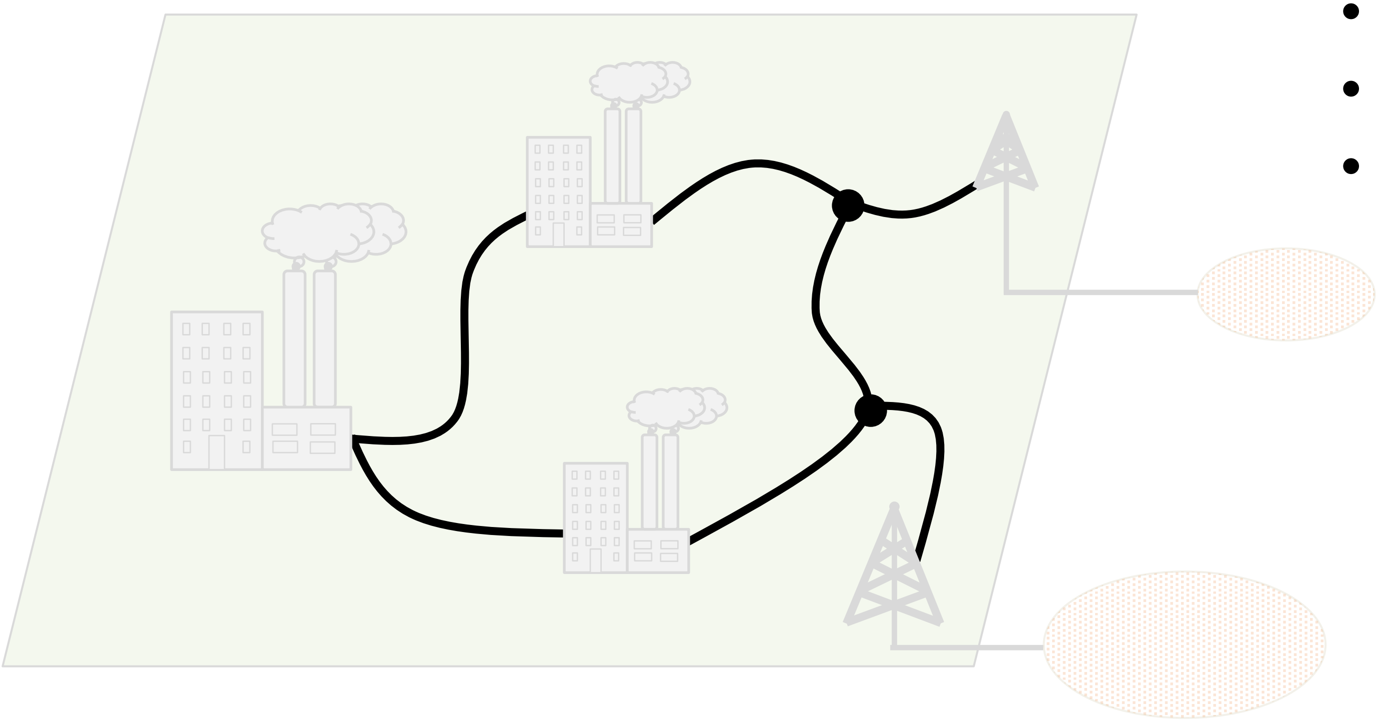


Storage:

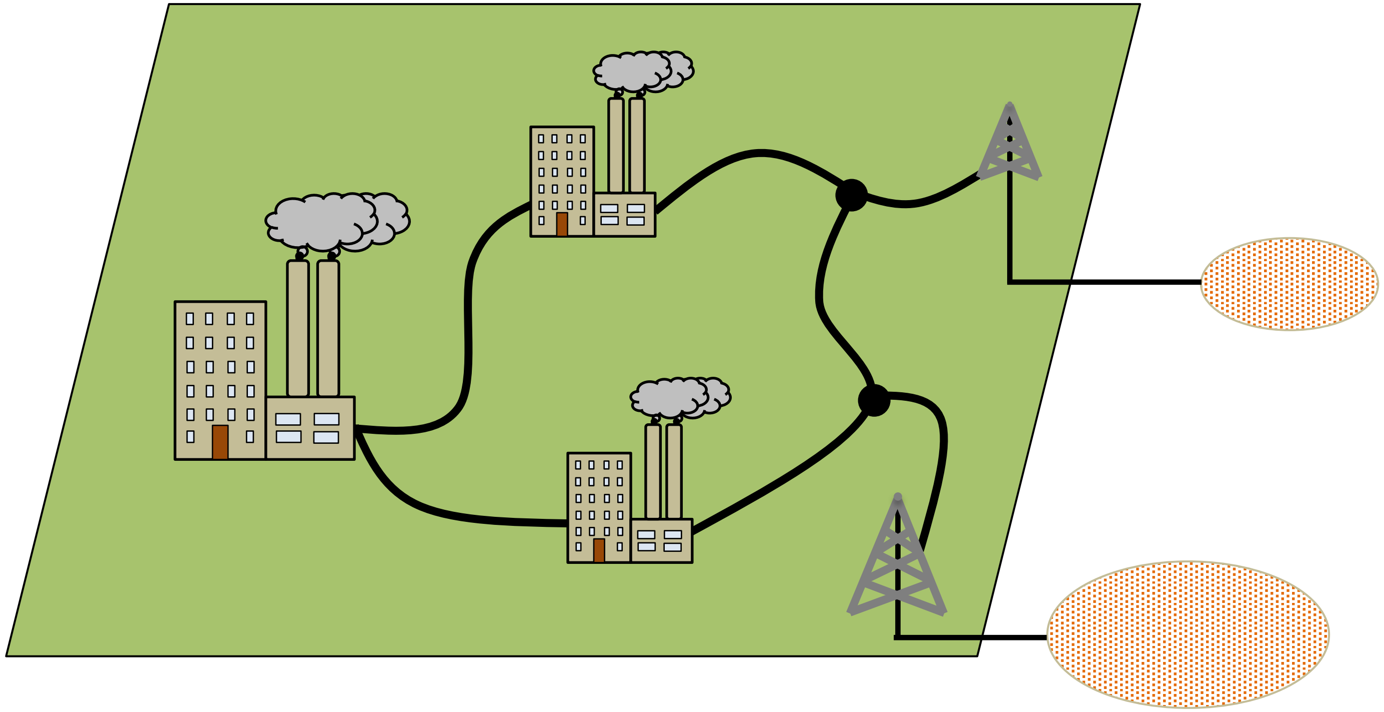
- Location
- Storage cost
- Storage capacity

Designing CCS Infrastructure

Transport:
- Location
- Construction cost
- Utilization cost
- Capacity



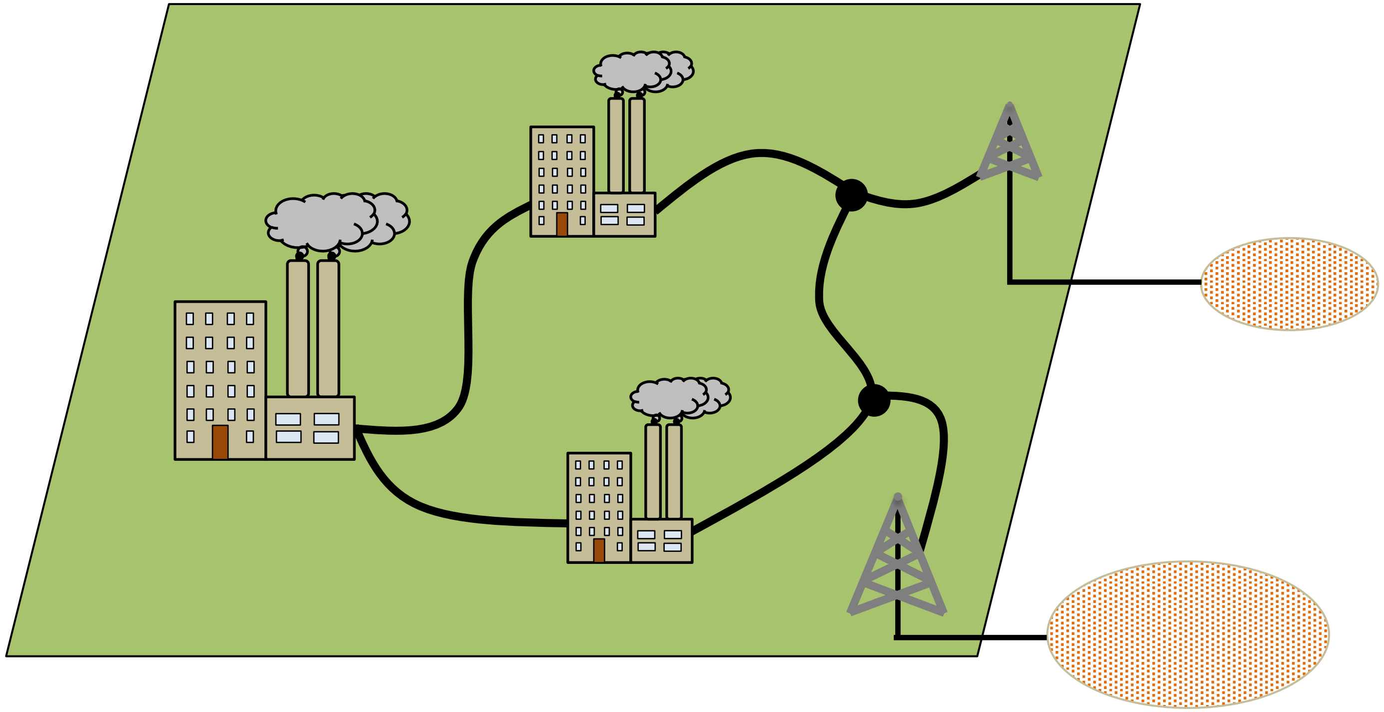
Designing CCS Infrastructure



CCS Infrastructure Design Decisions

- **Which sources to use?**
- **Which reservoirs to use?**
- **Where to build pipelines?**

Designing CCS Infrastructure

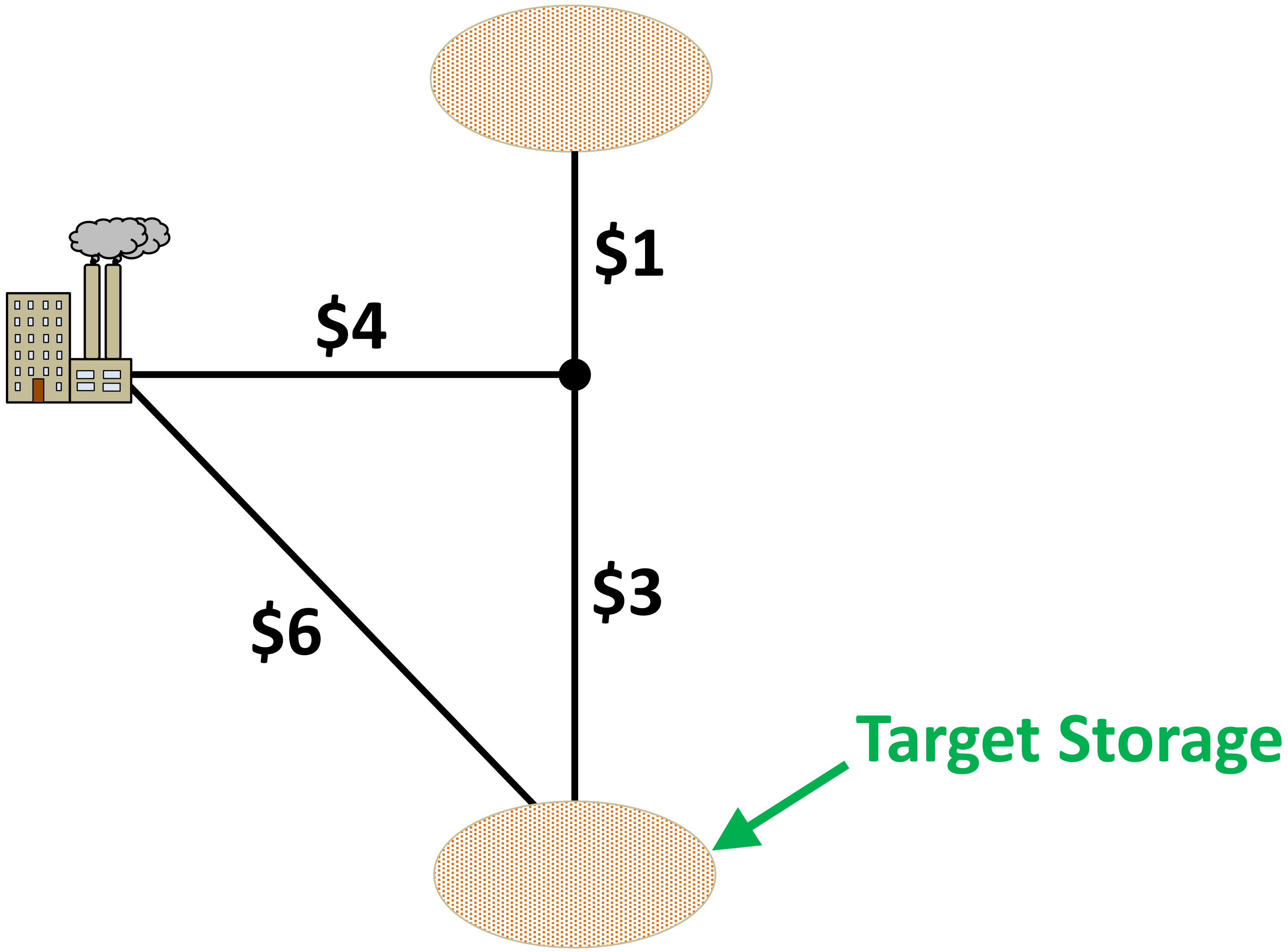


***SimCCS*: Finds the least cost infrastructure that supports the objectives.**

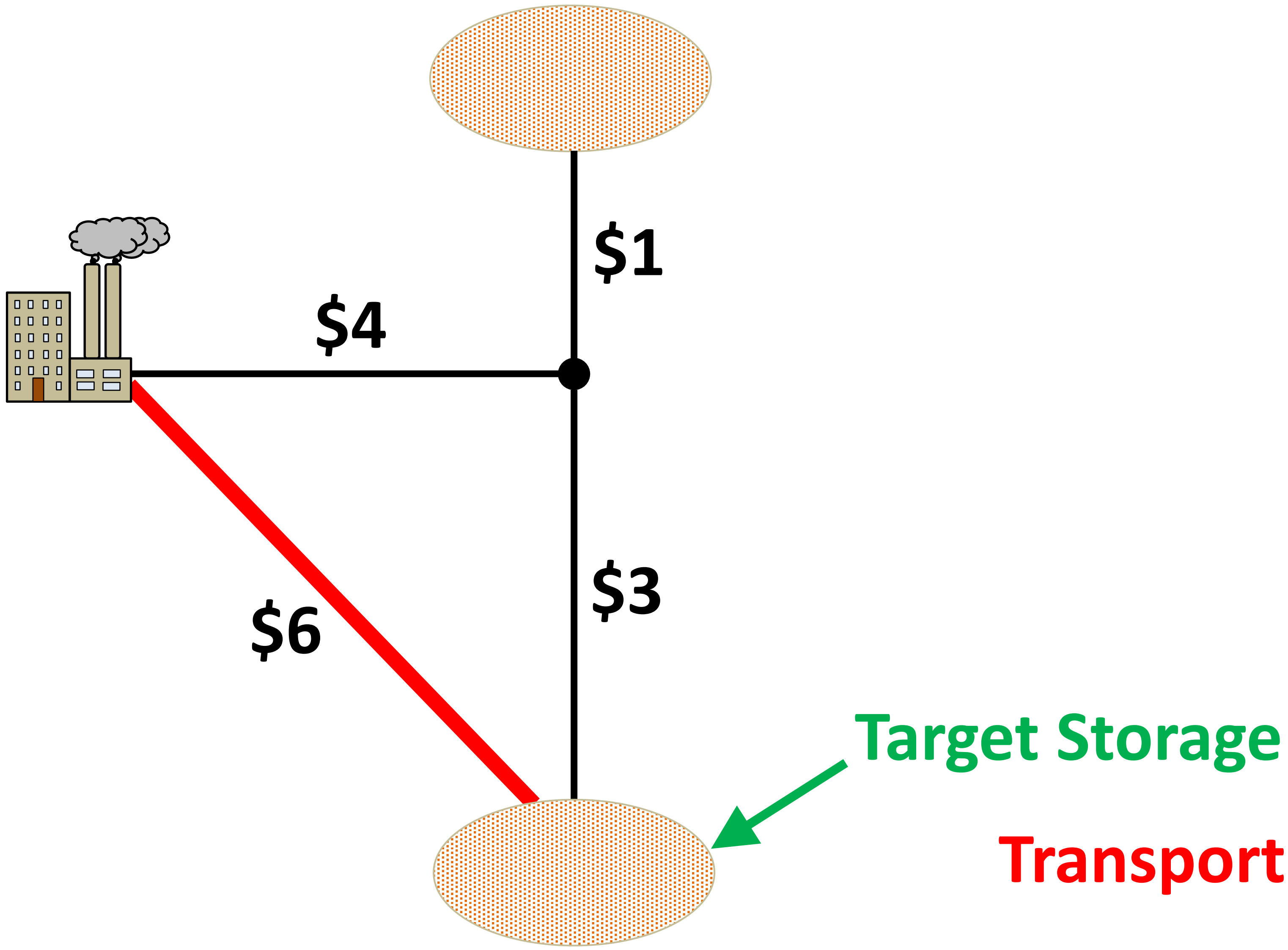
CCS Infrastructure Design Decisions

- **Which sources to use?**
- **Which reservoirs to use?**
- **Where to build pipelines?**

Uncertainty Motivation

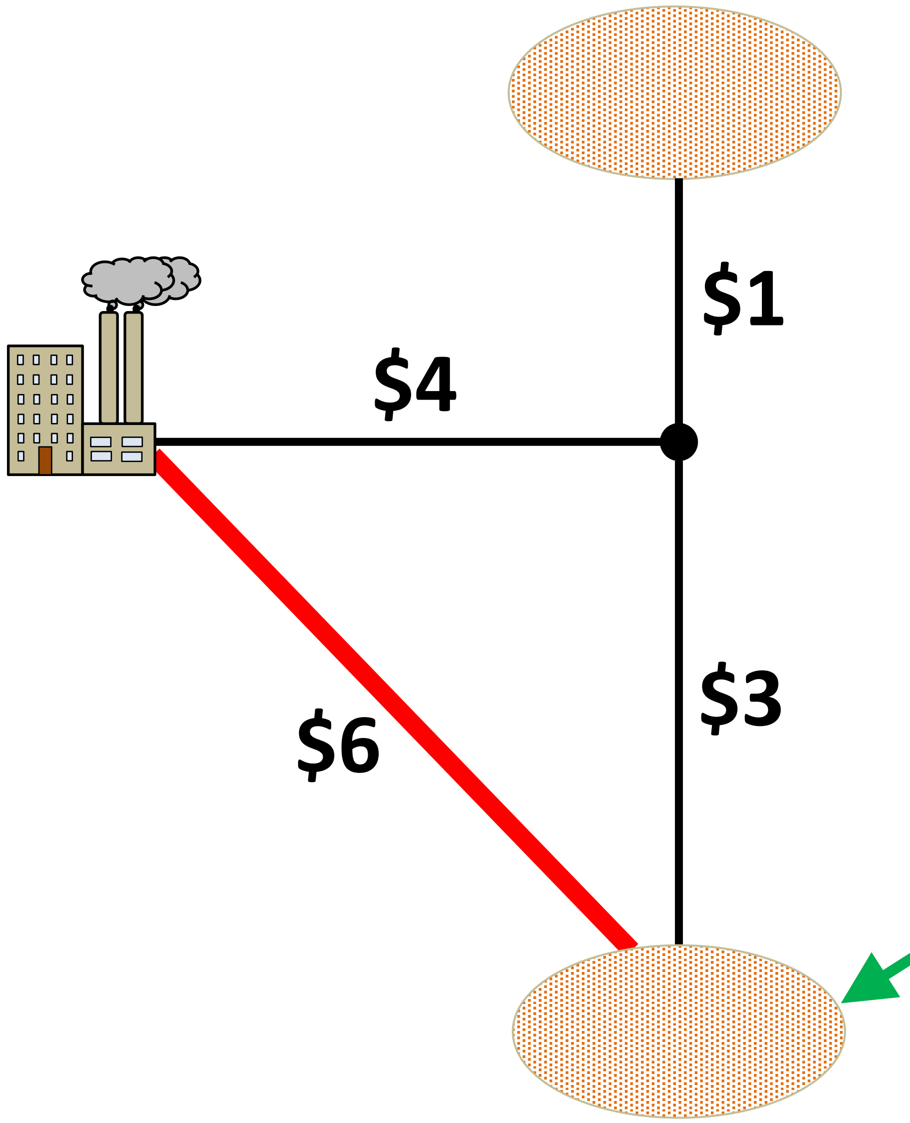


Uncertainty Motivation



Transport Cost: $6

Uncertainty Motivation

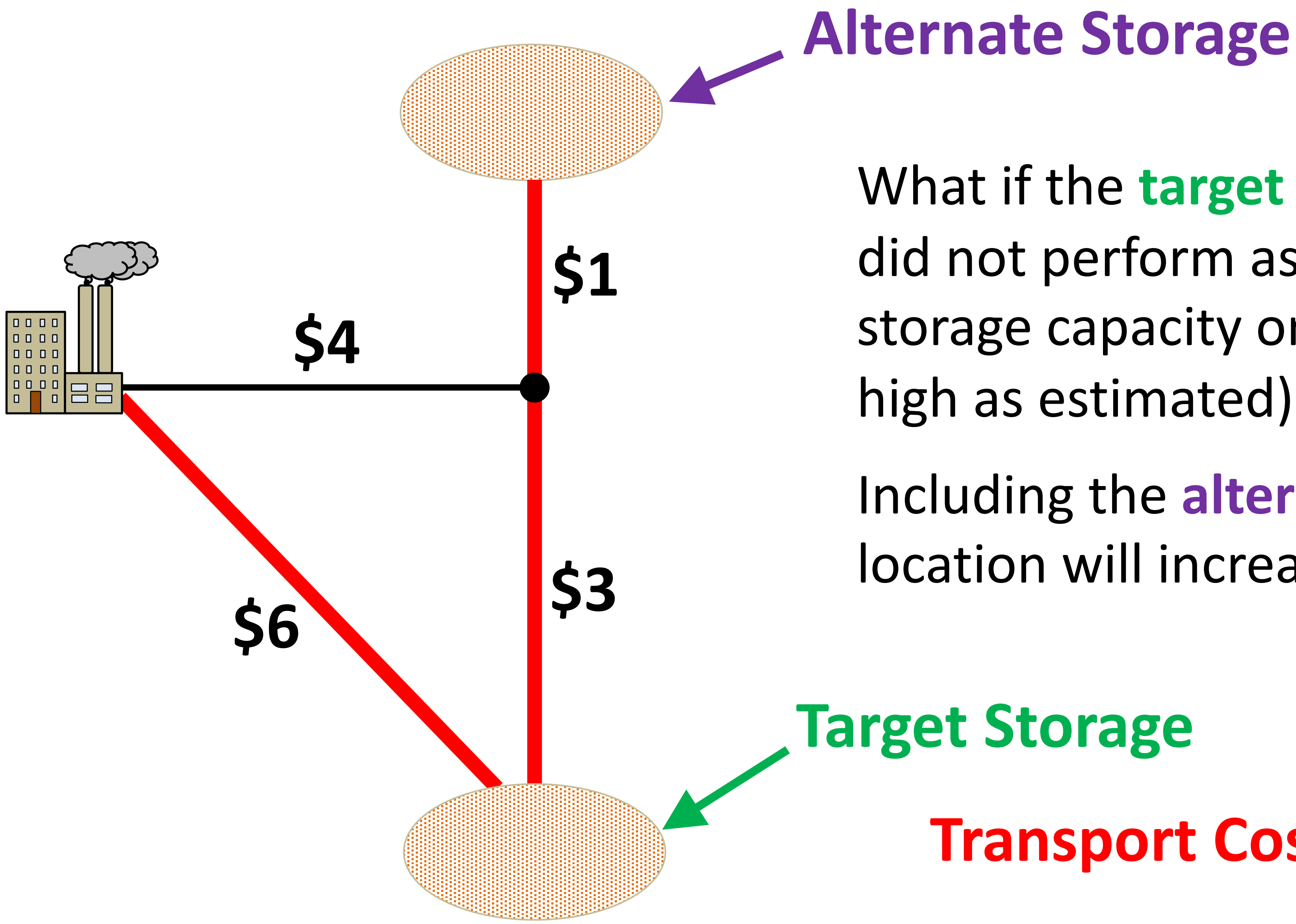


What if the **target storage** location did not perform as anticipated (e.g., storage capacity or injectivity not as high as estimated)?

Target Storage

Transport Cost: $6

Uncertainty Motivation

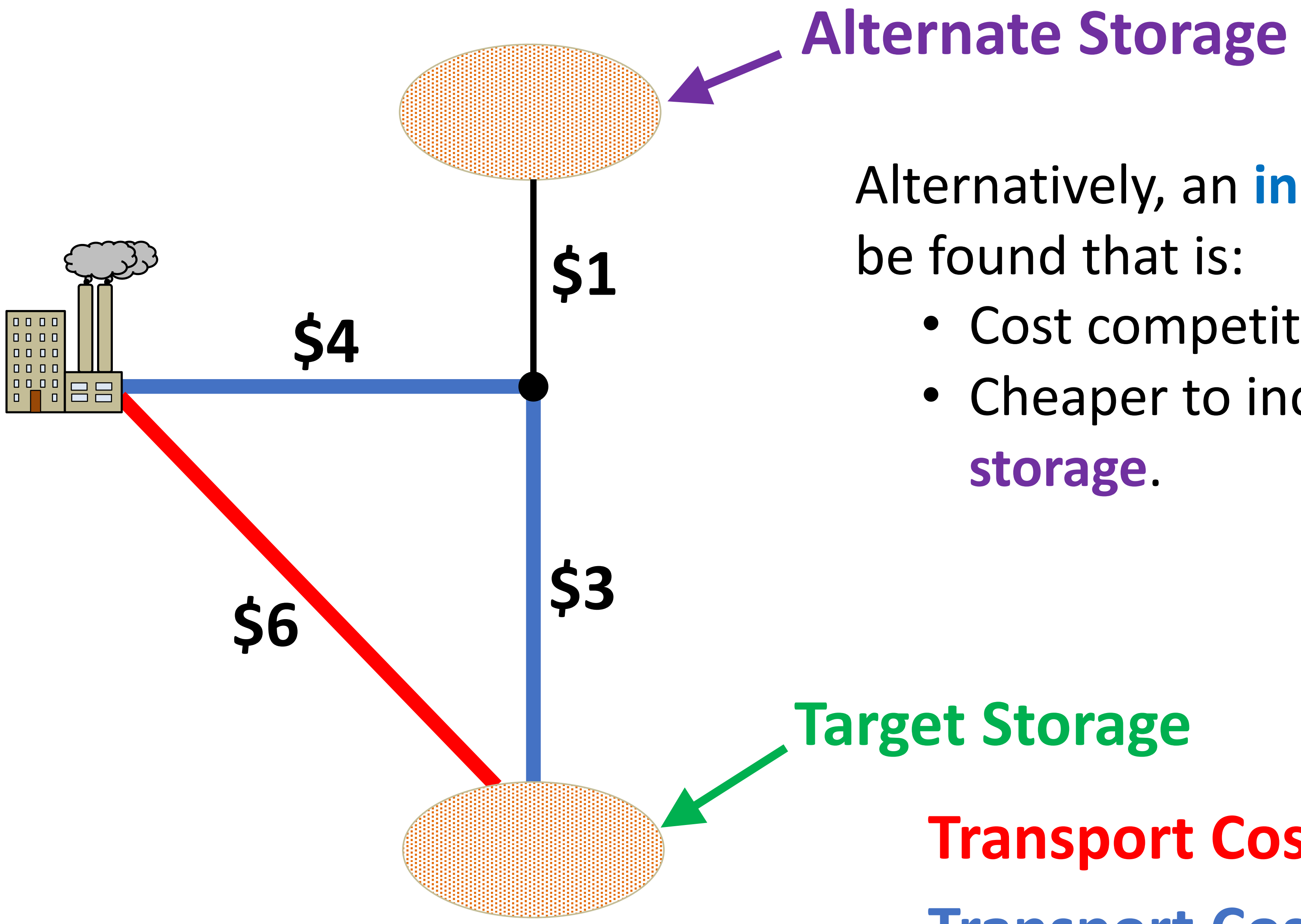


What if the **target storage** location did not perform as anticipated (e.g., storage capacity or injectivity not as high as estimated)?

Including the **alternate storage** location will increase cost.

Transport Cost: $6 + $4

Uncertainty Motivation



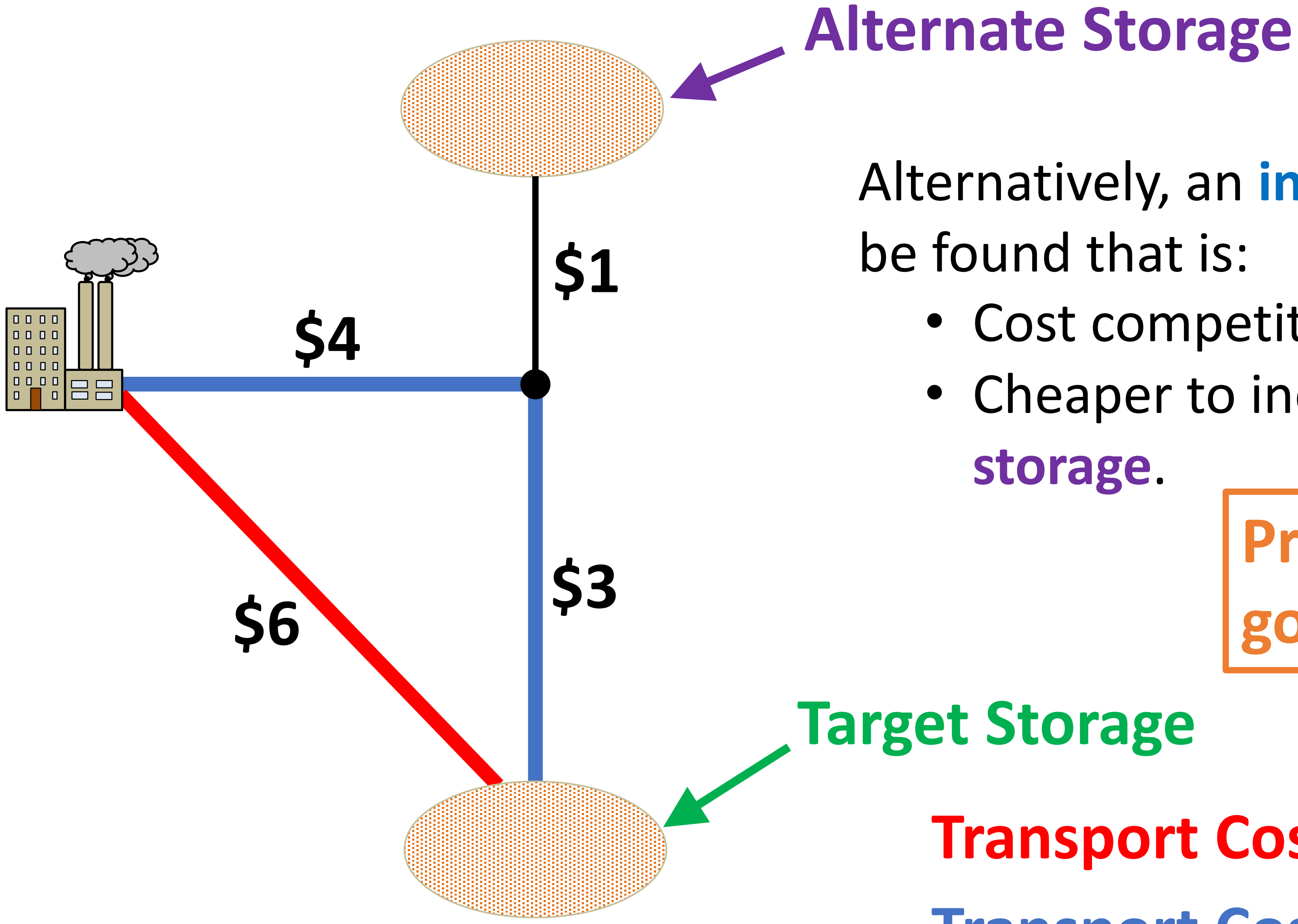
Alternatively, an **initial design** can be found that is:

- Cost competitive.
- Cheaper to include **alternate storage**.

Transport Cost: $6 ($10)

Transport Cost: $7 ($8)

Uncertainty Motivation



Alternatively, an **initial design** can be found that is:

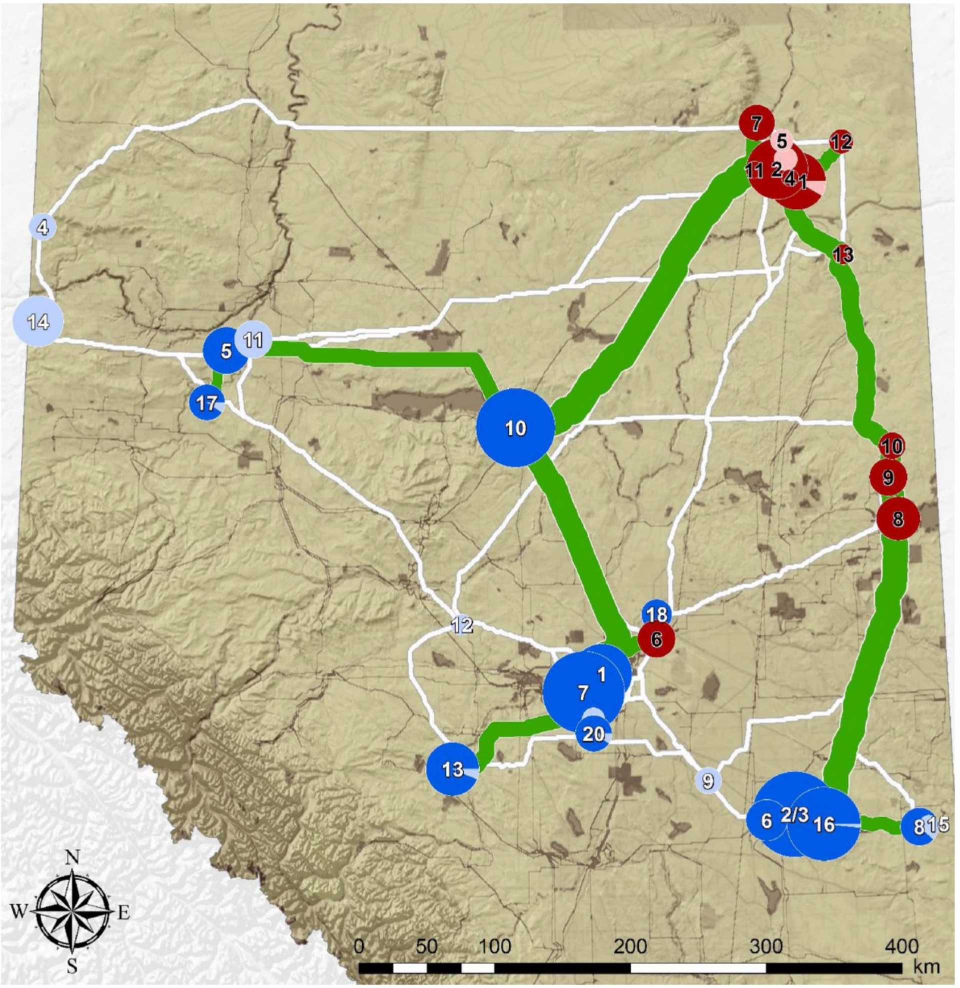
- Cost competitive.
- Cheaper to include **alternate storage**.

Project Goal: Find good initial designs.

Transport Cost: $6 ($10)

Transport Cost: $7 ($8)

Previous Work

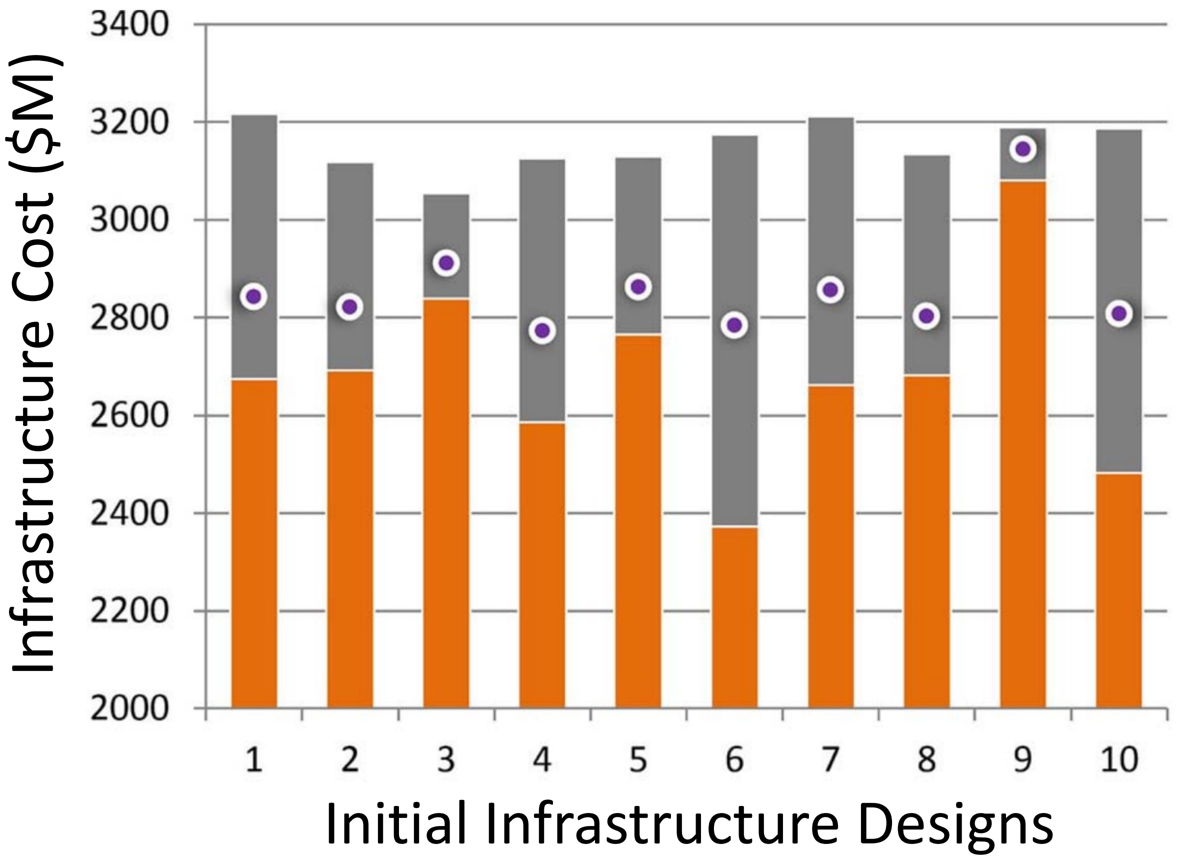


2018 study*:

- Designed optimal infrastructure for set of scenarios.
- Calculated cost for each solution to accommodate all other scenarios.

*Middleton, R.S., Yaw, S., 2018. The cost of getting CCS wrong: uncertainty, infrastructure design, and stranded CO_2. *International Journal of Greenhouse Gas Control*.

Previous Work



2018 study*:

- Designed optimal infrastructure for set of scenarios.
- Calculated cost for each solution to accommodate all other scenarios.
- Quantified impacts of storage uncertainty on infrastructure performance/cost.

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Current Work

Current Work

- Identifying priorities for uncertainty assessment (e.g., **storage cost**, **storage capacity**, **capture cost**).

$$\min \overbrace{\sum_{i\in S}(F_i^s s_i + V_i^s a_i)}^{capture\ cost} + \overbrace{\sum_{k\in K}\sum_{c\in C}\alpha_{kc}p_{kc}}^{pipeline\ use\ cost} + \overbrace{\sum_{k\in K}\sum_{c\in C}\beta_{kc}y_{kc}}^{pipeline\ build\ cost} + \overbrace{\sum_{j\in R}(F_j^r r_j + F_j^w w_j + V_j^w b_j)}^{storage\ cost}$$

subject to the following constraints:

$$Q_{kc}^{\min} y_{kc} \le p_{kc} \le Q_{kc}^{\max} y_{kc}, \forall k \in K, \forall c \in C \tag{A}$$

$$\sum_{c\in C} y_{kc} \le 1, \forall k \in K \tag{B}$$

$$\sum_{\substack{k\in K:\\ src(k)=i}}\sum_{c\in C} p_{kc} - \sum_{\substack{k\in K:\\ dst(k)=i}}\sum_{c\in C} p_{kc} = \begin{cases} a_i & \text{if } i \in S \\ -b_i & \text{if } i \in R \\ 0 & \text{otherwise} \end{cases}, \forall i \in I \tag{C}$$

$$a_i \le Q_i^s s_i, \forall i \in S \tag{D}$$

$$b_j \le Q_j^w w_j, \forall j \in R \tag{E}$$

$$b_j \le Q_j^r r_j, \forall j \in R \tag{F}$$

$$\sum_{i\in S} a_i \ge \mathrm{CO_2Cap} \tag{G}$$

Current Work

- Identifying priorities for uncertainty assessment (e.g., storage cost, storage capacity, capture cost).

- Exploring techniques for endogenously integrating uncertainty into model (e.g., distributionally robust optimization).

$$\min \overbrace{\sum_{i\in S}\left(F_i^s s_i + V_i^s a_i\right)}^{capture\ cost} + \overbrace{\sum_{k\in K}\sum_{c\in C}\alpha_{kc}p_{kc}}^{pipeline\ use\ cost} + \overbrace{\sum_{k\in K}\sum_{c\in C}\beta_{kc}y_{kc}}^{pipeline\ build\ cost} + \overbrace{\sum_{j\in R}\left(F_j^r r_j + F_j^w w_j + V_j^w b_j\right)}^{storage\ cost}$$

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Current Work

- Identifying priorities for uncertainty assessment (e.g., storage cost, storage capacity, capture cost).
- Exploring techniques for endogenously integrating uncertainty into model (e.g., distributionally robust optimization).
- Modifying code to serve as testbed for various approaches being developed.

$$\min \overbrace{\sum_{i\in S}\left(F_i^s s_i + V_i^s a_i\right)}^{capture\ cost} + \overbrace{\sum_{k\in K}\sum_{c\in C}\alpha_{kc}p_{kc}}^{pipeline\ use\ cost} + \overbrace{\sum_{k\in K}\sum_{c\in C}\beta_{kc}y_{kc}}^{pipeline\ build\ cost} + \overbrace{\sum_{j\in R}\left(F_j^r r_j + F_j^w w_j + V_j^w b_j\right)}^{storage\ cost}$$

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