



Environment, Energy, and Economic Development Program

Estimation of Regional Air-Quality Damages from Unconventional Shale Gas Extraction: A Case Study in Pennsylvania

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*Seminar for the Center for Climate and Energy Decision Making (CEDM)
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Shale Gas Resources Have Changed the Energy Outlook in the United States

- **Natural gas is a versatile fuel, used to:**
 - **Produce electricity**
 - **Provide residential and commercial heating**
 - **Generate industrial process steam and heat**
- **Natural gas is relatively clean burning**
 - **Low criteria pollutants**
 - **Half the greenhouse-gas intensity of coal**
- **The U.S. natural gas supply has increased due to access to unconventional resources, such as gas trapped in shale deposits**

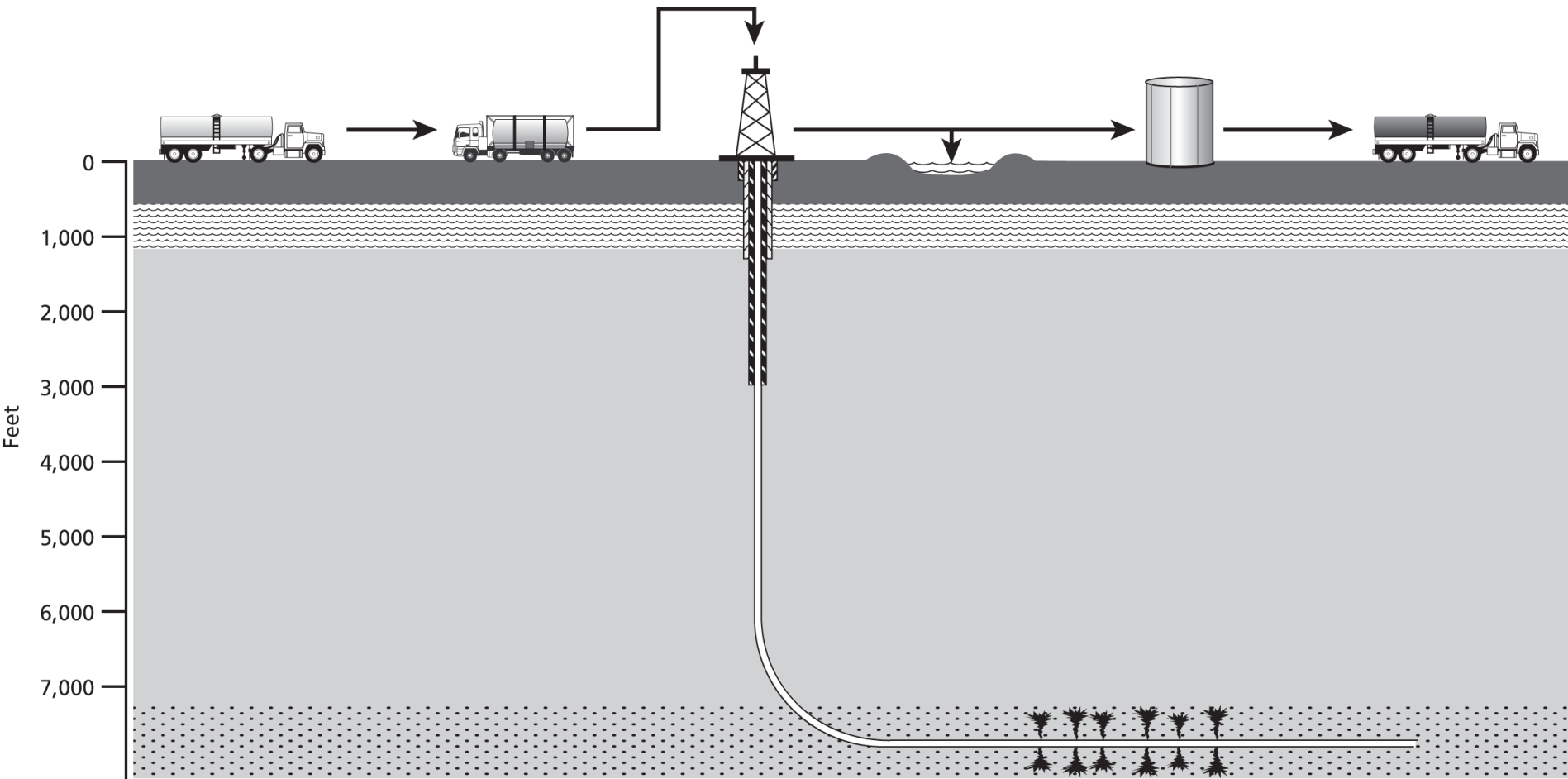
The Marcellus Shale Formation is a Major Natural Gas Resource for the United States



SOURCE: Adapted from U.S. Geological Survey.

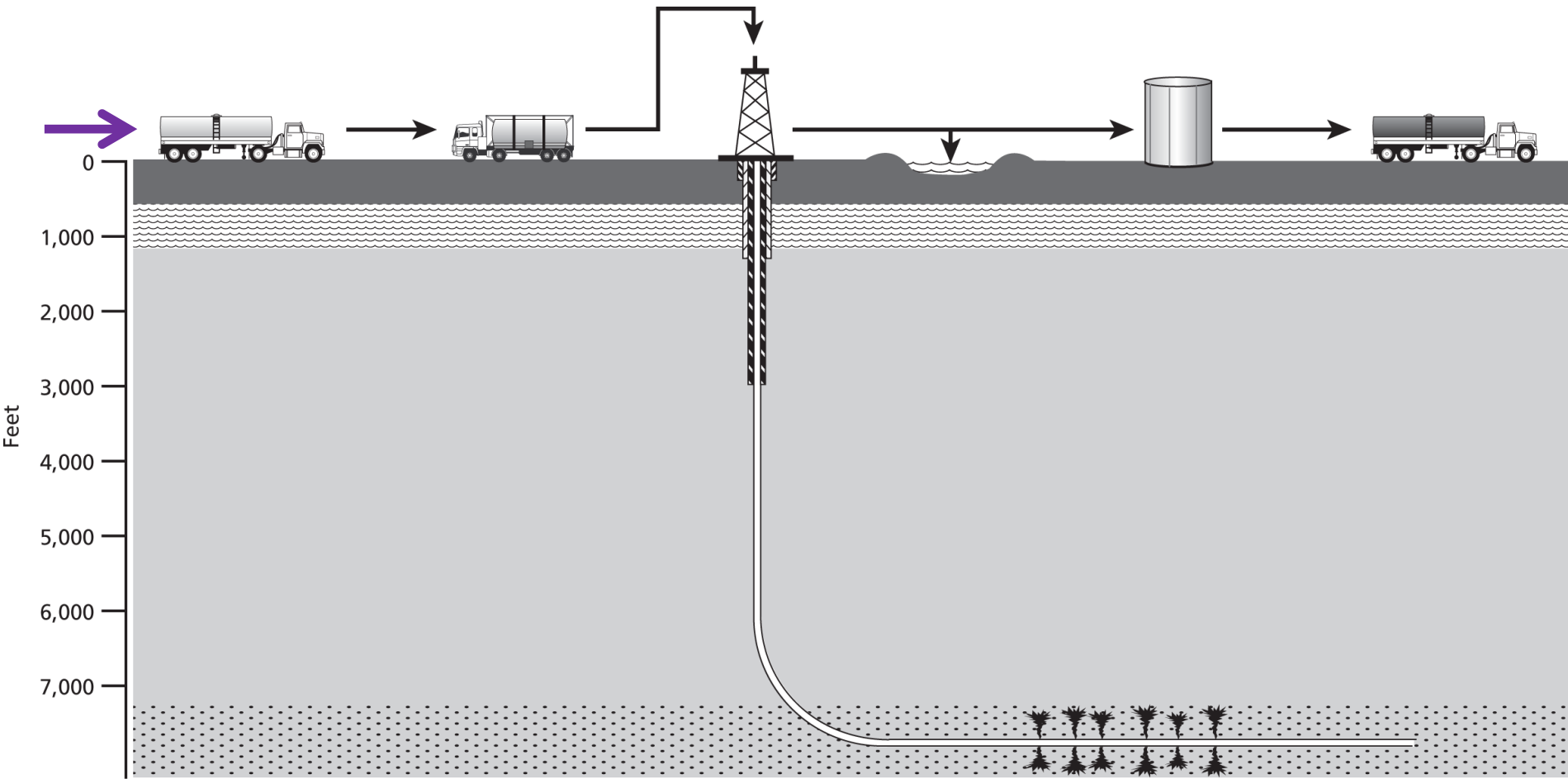
Technically recoverable reserves: ~140 trillion cubic feet (Tcf)

Horizontal Drilling and Hydraulic Fracturing Releases Natural Gas Trapped in Shale



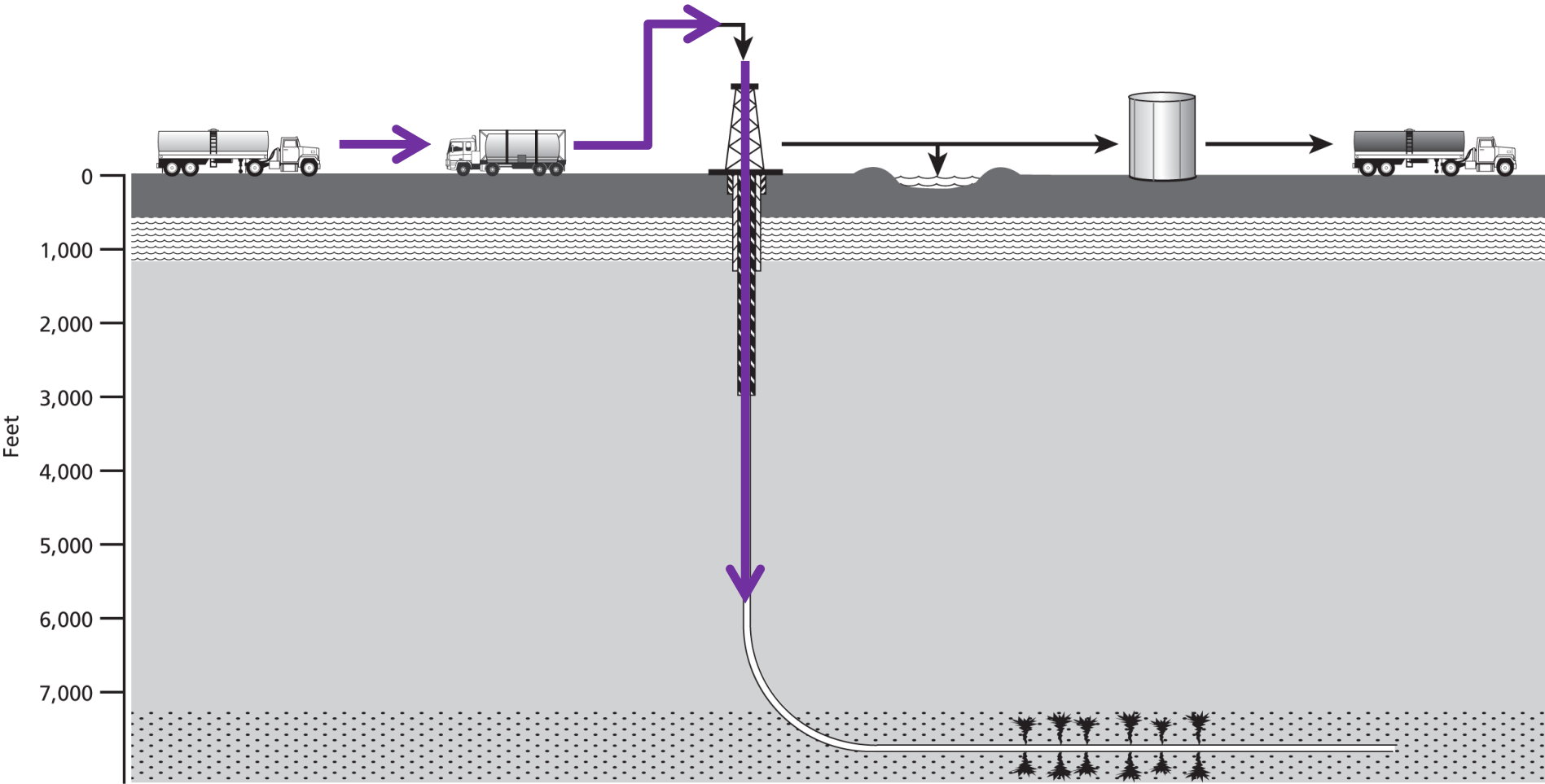
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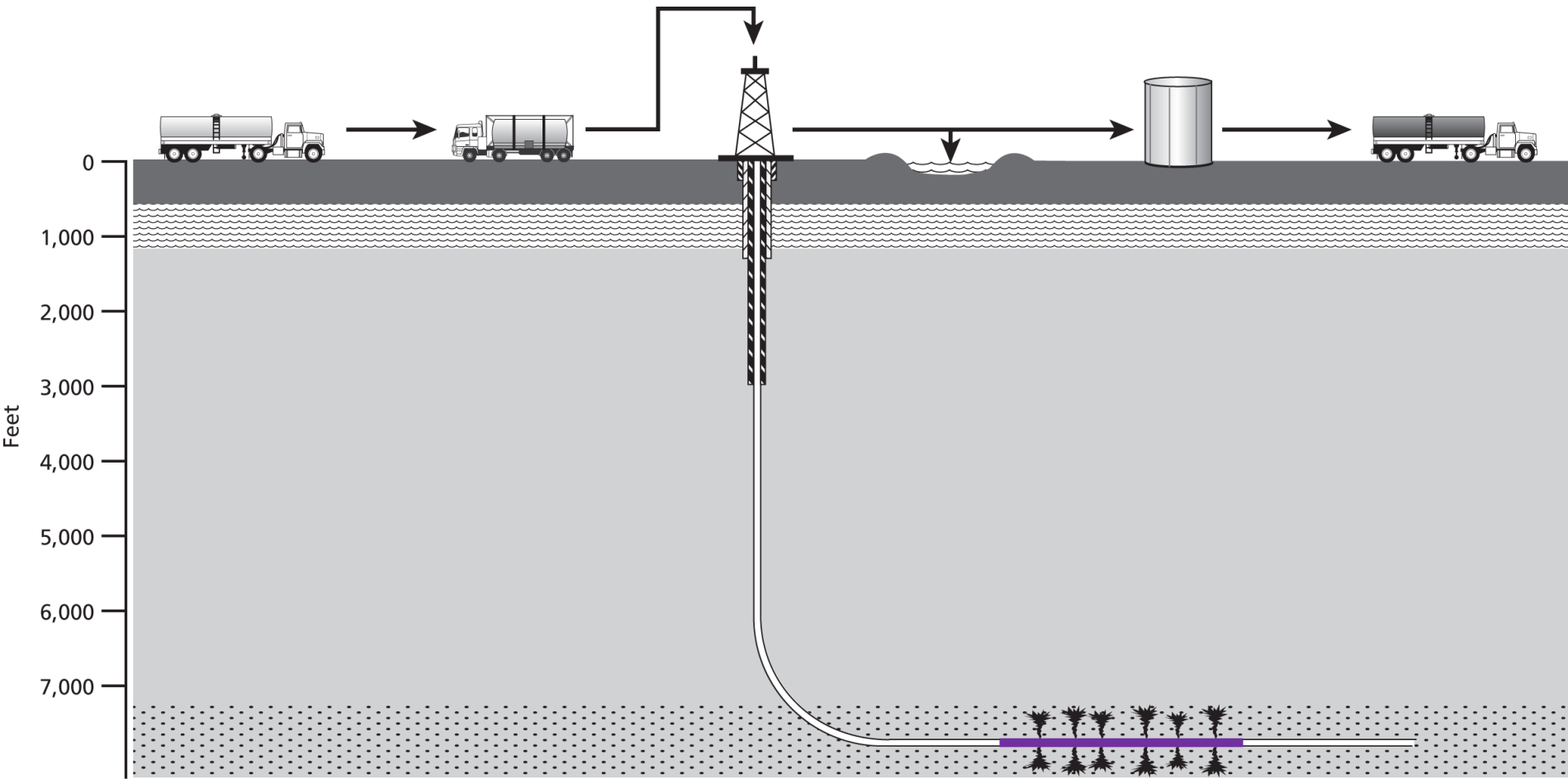
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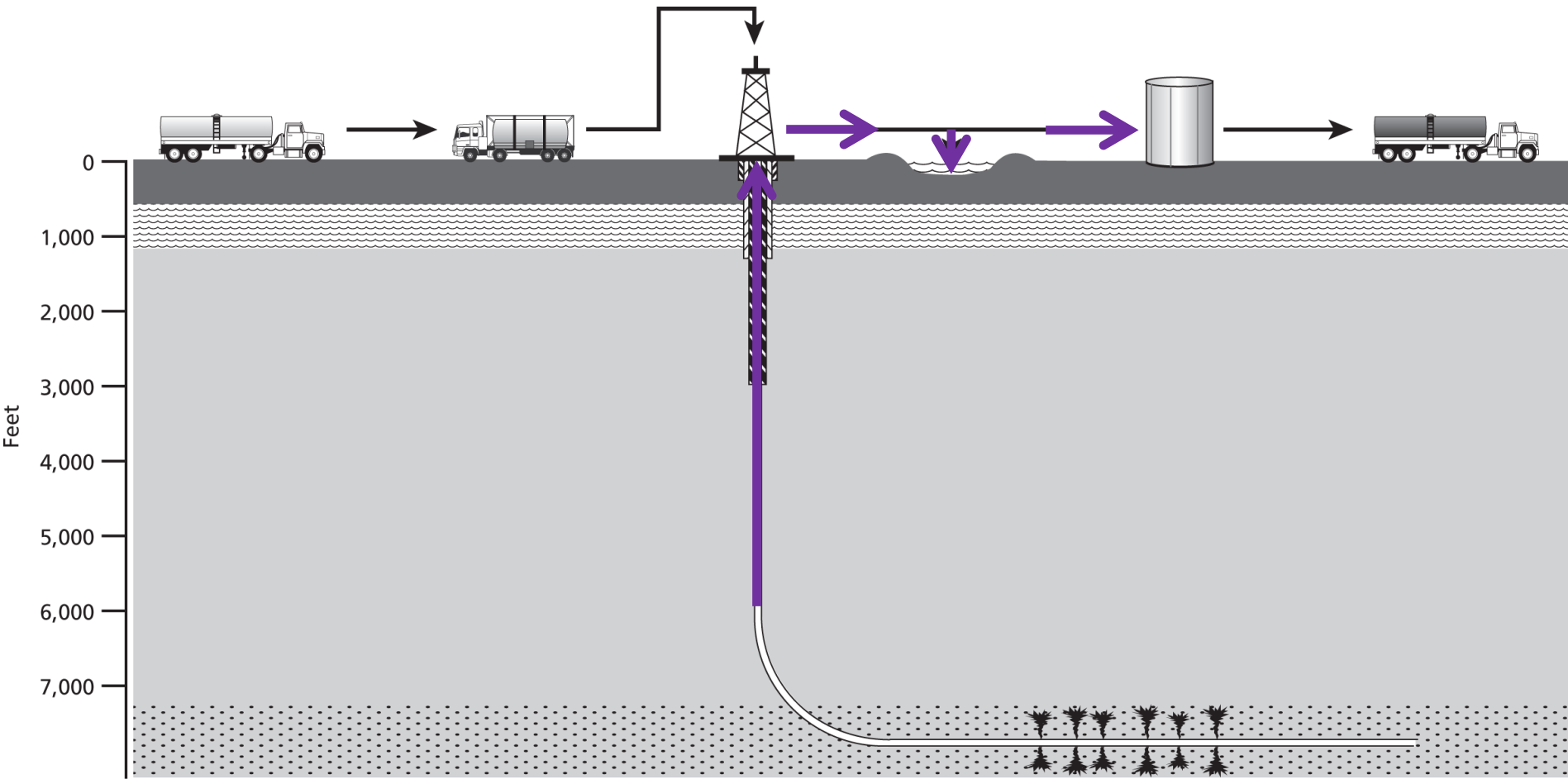
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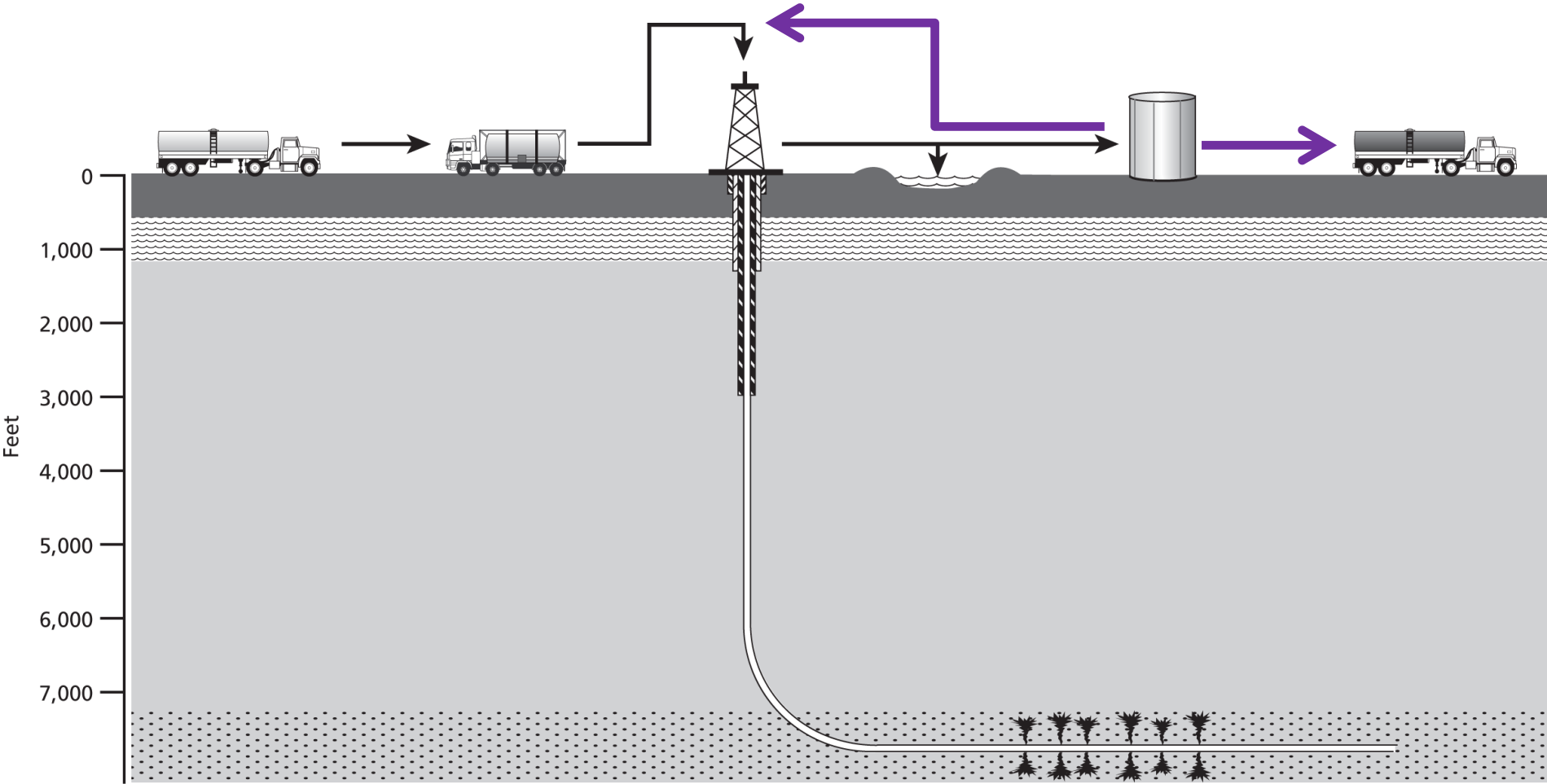
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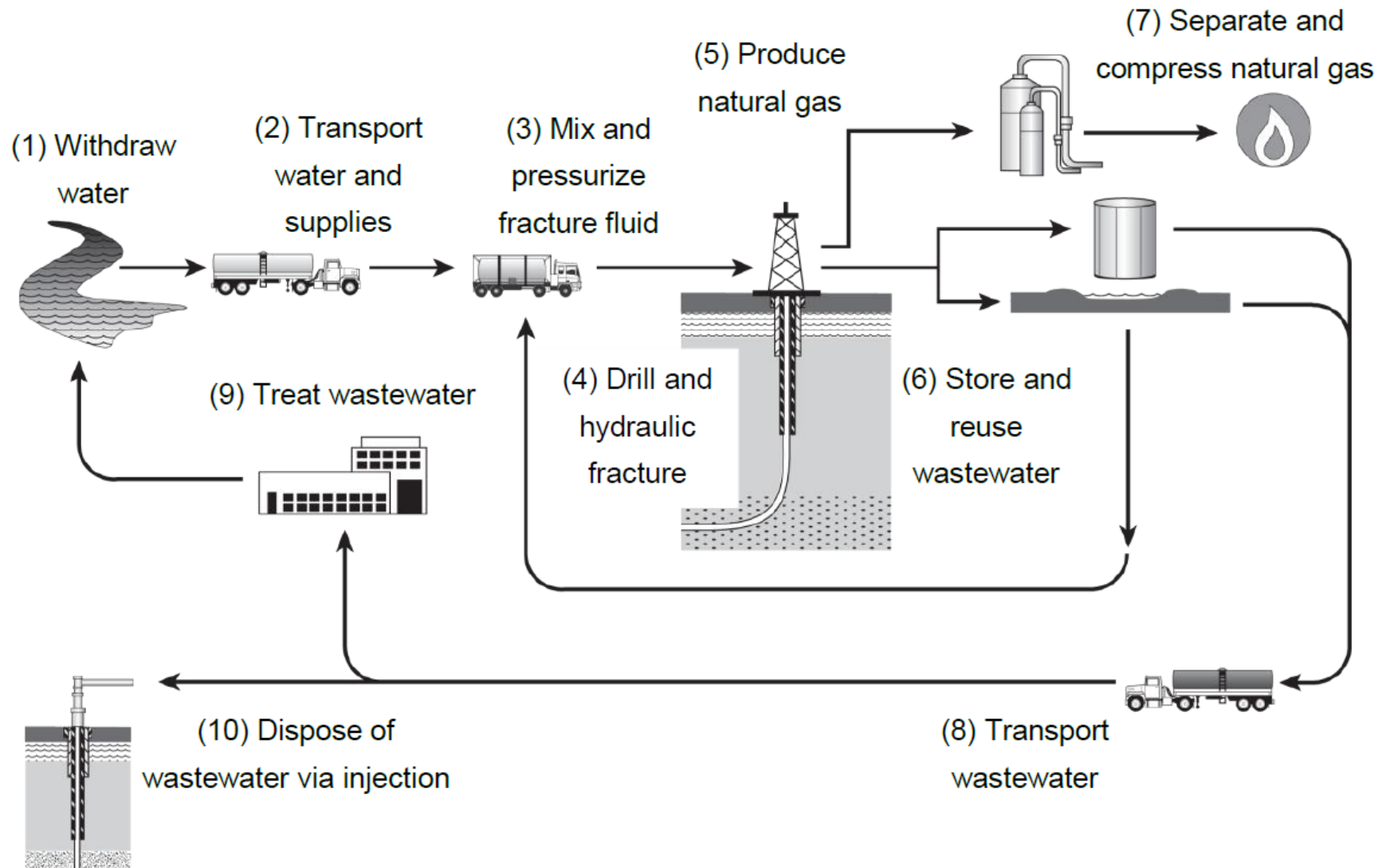
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Schematic of the Major Steps of Shale Gas Extraction Considered in Our Analysis



Extracting and Using Natural Gas from Shale Has Regional and Local Policy Implications

- **Shale gas provides benefits**
 - **Lower energy costs**
 - **Direct and indirect economic activity and jobs**
 - **Wealth generation for individuals**
 - **Tax and impact fee revenue**
 - **Reductions in electricity emissions (vs. coal)**
- **Shale gas extraction also imposes external costs**
- **Impact fees can be used to reduce external costs and can generate revenue**

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Our analysis focuses on external costs important to regional and local stakeholders in Pennsylvania

RAND Assessed the External Costs of Shale Gas Extraction in the Commonwealth

- **Identified categories of risks**
- **Assessed the (relative) magnitude and likelihood of each risk**
- **When possible, estimated the monetized cost of each risk**

We Looked at Three Major Risk Categories, And Today We Focus on Air Quality Impacts

- **Overview of risks leading to potential externalities**
- **Discuss our analysis of**
 - **Road damage**
 - **Increased air emissions and related damages**
 - **Risks to water, quantity and quality**
- **Policy implications and epilogue**

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There Are A Range of Potentially Significant External Costs from Shale Gas Extraction

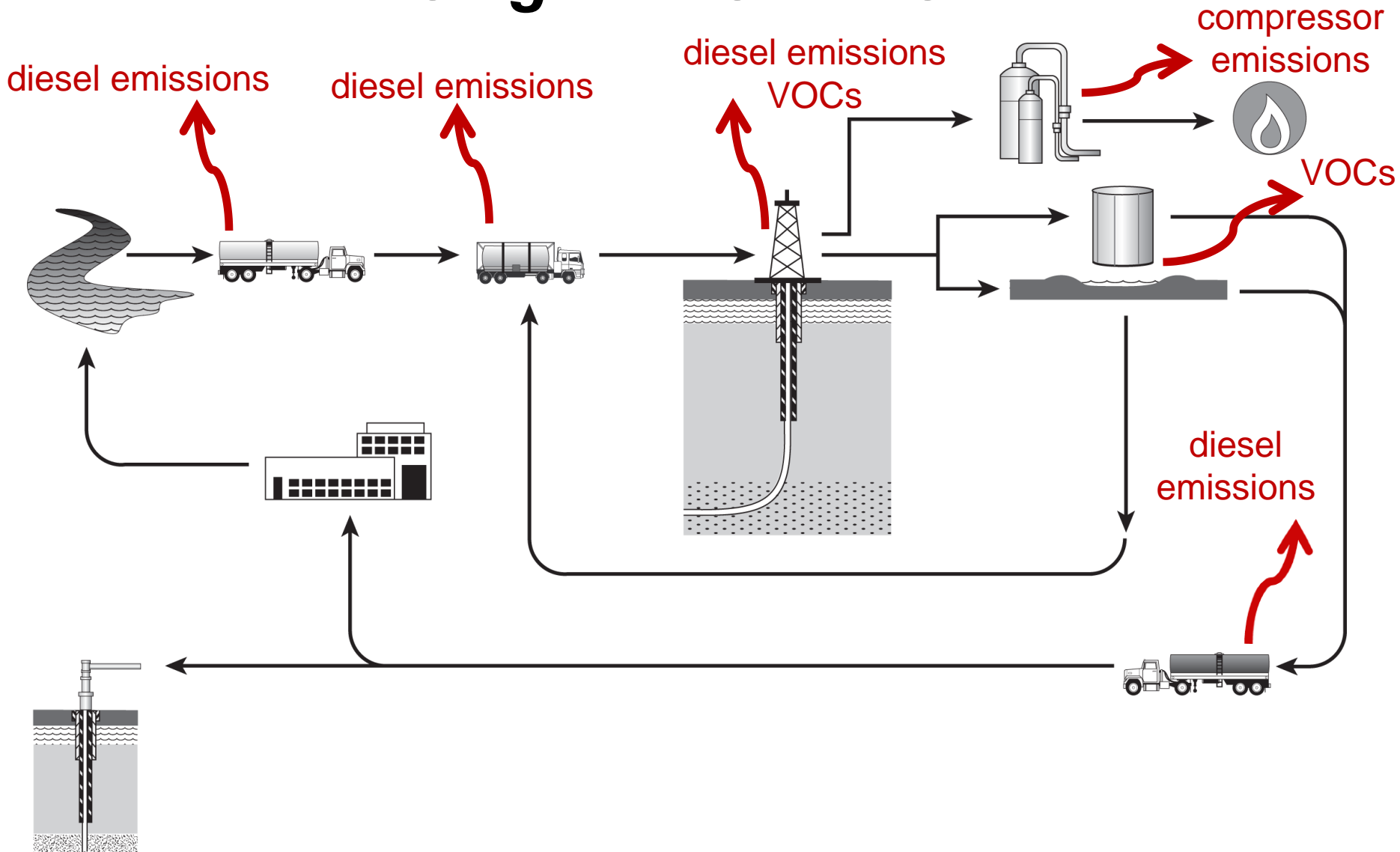
- **Water use and water pollution**
- **Air pollution**
- **Infrastructure damage**
- **Adverse community impacts**
- **Damage to ecosystems and agriculture**
- **Also leads to increased demands on public services, regulatory agencies**

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*“Estimation of regional air-quality damages from Marcellus Shale natural gas extraction in Pennsylvania”, Aviva Litovitz *et al* 2013 *Environ. Res. Lett.* 8 014017

Conventional Air Pollutants Are Emitted Across Most Stages of Shale Gas Production



Emissions Can Impact Local and Regional Air Quality, With Health Implications

- **Types and sources of pollutants include**
 - **VOCs: diesel combustion; venting and flaring; leaks/spills**
 - **NO_x: diesel and natural gas combustion**
 - **PM_{2.5}, PM₁₀: diesel combustion; road dust; reaction of SO₂ (indirect)**
 - **SO₂: diesel combustion**
 - **O₃: reaction of NO_x and VOCs (indirect)**
- **Damages include**
 - **Adverse respiratory effects, reduced lung function, aggravation of heart disease, premature death**
 - **Increased illness and hospital admissions**
 - **Infrastructure, ecosystem/agriculture, aesthetic impacts**

We Estimated Air Emissions and Associated Health and Environmental Damages

- **Estimates included 4 major activities**
 1. **Transport**
 2. **Well drilling and hydraulic fracturing**
 3. **Natural gas production**
 4. **Compressor stations**
- **Sources of emissions estimates were**
 - **Published literature**
 - **Industry reports to PA DEP**
 - **PA DEP permit applications**
- **Emissions were translated into damages**
 - **County-specific emissions were calculated**
 - **Regional damages compared to other sectors**

In 2011, Regional Damages from Extraction Industry Emissions Were Millions of Dollars

Table 6. Estimates of Regional Air Pollution Damages from Pennsylvania Extraction Activities in 2011

Activities	Timeframe/ Boundaries	Total Regional Damage for 2011 (\$2011)	Average Per Well or Per MMCF Damage (\$2011)
1. Transport to and from Well-Site	Development	\$320,000 - \$810,000	\$180 - \$460 per well
2. Well Drilling, Hydraulic Fracturing	Development	\$2,200,000- \$4,700,000	\$1,200 – \$2,700 per well
3. Production	Ongoing	\$290,000-\$2,700,000	\$0.27 – \$2.60 per MMCF
4. Compressor Stations	Ongoing	\$4,400,000 - \$24,000,000	\$4.20 - \$23.00 per MMCF
1-4. Aggregated	Development and Ongoing	\$7,200,000 - \$32,000,000	NA

- *Approximate per-well damages: ~\$4,000 to 18,000*

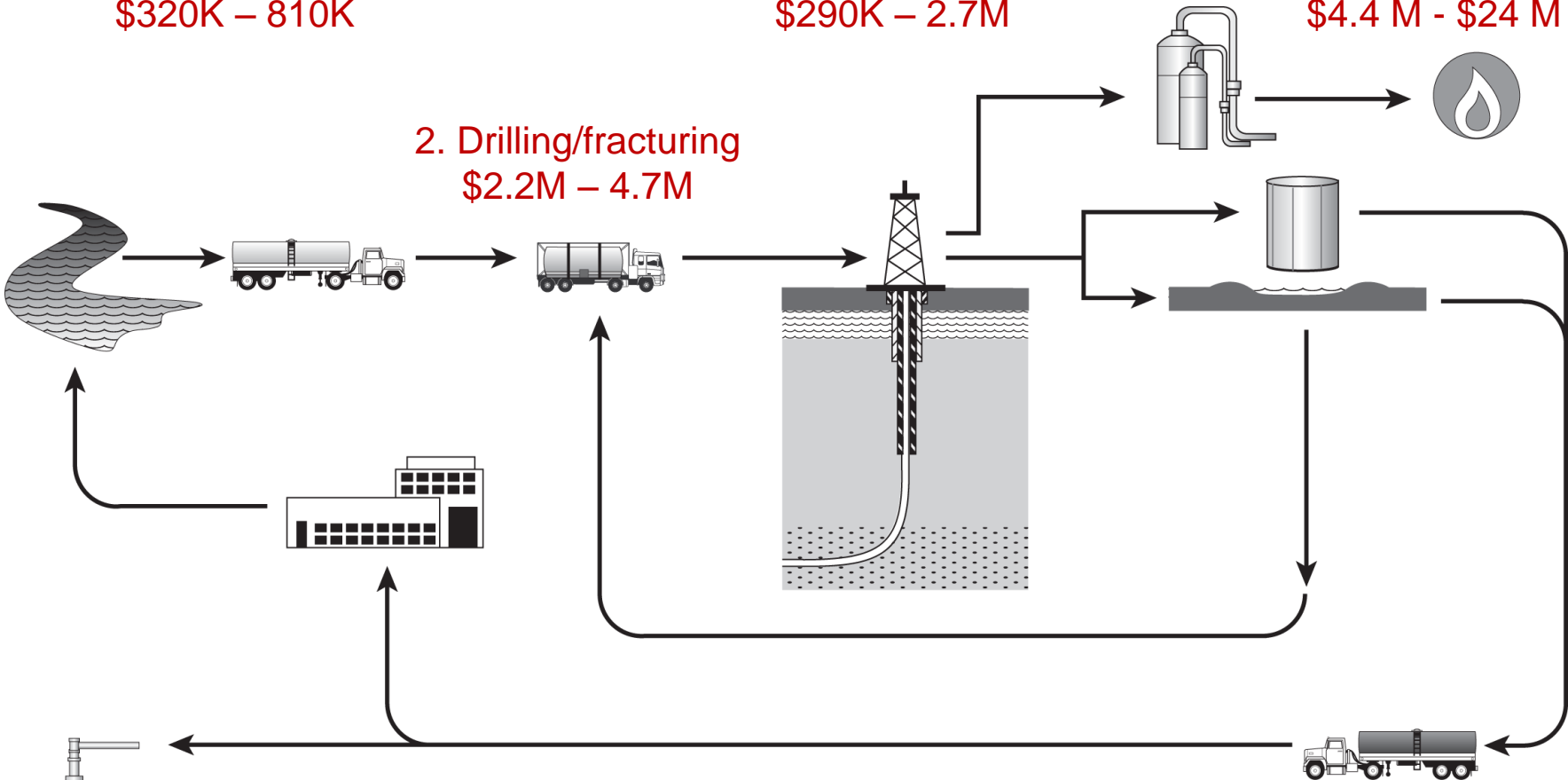
Sources and Statewide Magnitude of Damages

1. Transport
\$320K – 810K

3. Production
\$290K – 2.7M

4. Compressors
\$4.4 M - \$24 M

2. Drilling/fracturing
\$2.2M – 4.7M



- 94% of damages due to VOCs, NO_x, and PM_{2.5}

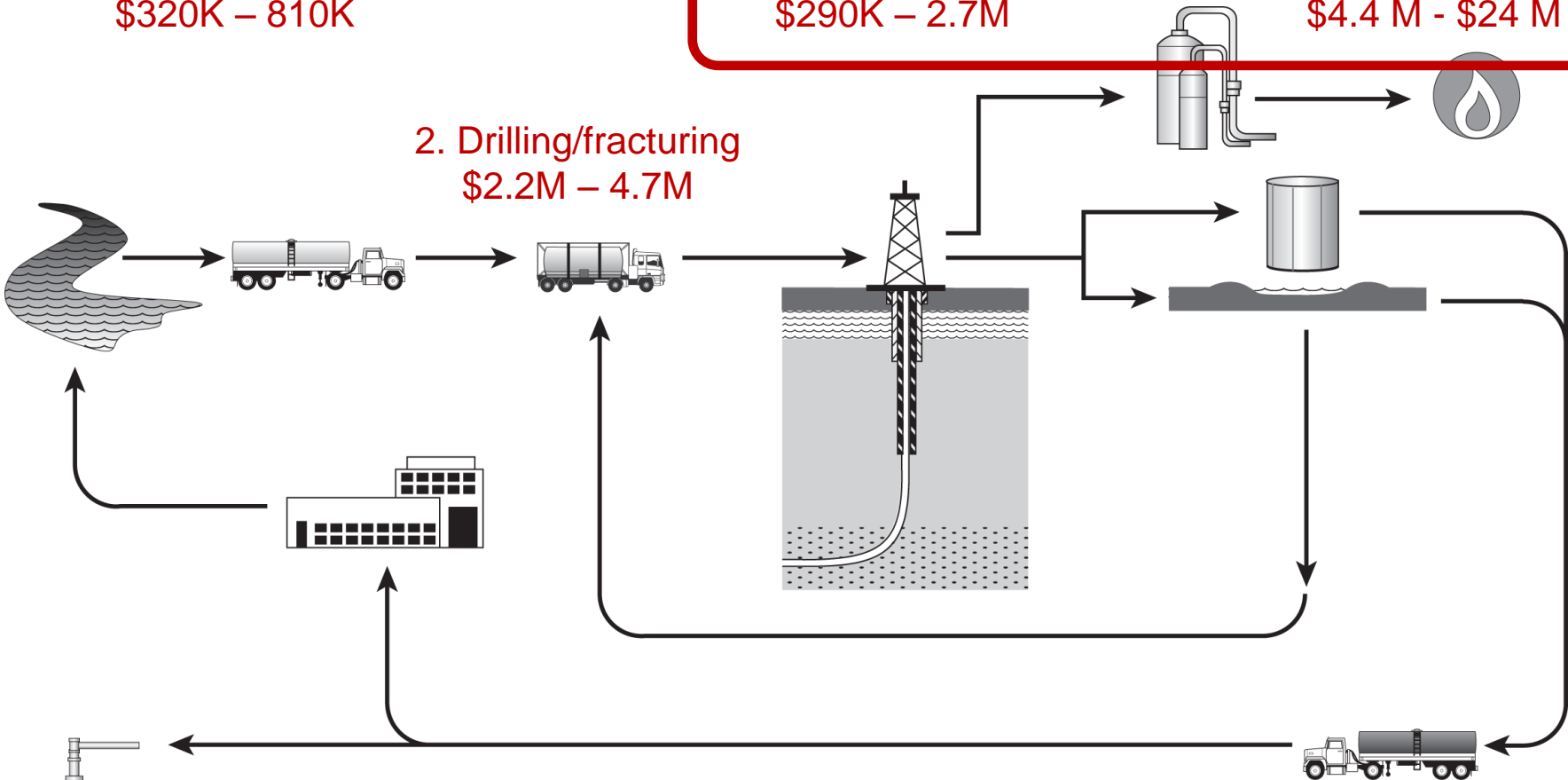
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- 94% of damages due to VOCs, NO_x, and PM_{2.5}
- 65-83% ongoing activities; 60-75% compressors

Overall Emissions Damages Are Relatively Small ... But of Concern in Some Locations

Table 7. Magnitude of Shale Gas Extraction Industry Relative to Air Pollutant Emissions from Other Industrial Sectors in Pennsylvania

Total Sector or Comparison	VOCs	NO_x	PM_{2.5}	PM₁₀	SO_x
Shale gas extraction industry in 2011, from Table 5 (metric tons)	2,500 – 11,000	17,000 – 28,000	460 – 1,400	460 – 1,400	12 – 540
Total, all sectors reporting (metric tons) ¹	720,000	579,000	134,000	322,000	898,000
Shale extraction relative to total (percent)	0.35 – 1.5%	2.9 – 4.8%	0.34 – 1.0%	0.14 – 0.43 %	0.0013 – 0.060%

- *Statewide VOC and NO_x on par with largest coal plants*

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- *>20% of wells in one county, ~90% in 10 counties*
- *Most active counties: 20-40 times the “major” source threshold*

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- *>20% of wells in one county, ~90% in 10 counties*
- *Most active counties: 20-40 times the “major” source threshold*
- *Largest damage attributable to one county: \$1.2 to 8.3 million... where nearby population is larger, baseline air quality is worse*

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Context of Act 13, PA's Impact Fee Legislation

- **Impact fee is specifically intended for costs of impacts to state and municipalities**
- **Fees are imposed on a per-well basis for a finite period of time, scale with the price of natural gas**
- **Counties where drilling occurs make the individual decision to opt in**
 - **Fee only collected, and revenue only distributed, in counties that opt in**
 - **Non-drilling counties will not directly benefit**

Problems May Exist with Impact Fee Rate, Use Restrictions, and Transboundary Costs

- **Optimal fee (Pigovian tax) should be set equal to marginal social damage, but damages are often difficult to estimate**
- **Revenue use is restricted, may not be properly aligned with impacts or allocated to optimal uses**
- **Potential external costs may extend beyond county and municipality boundaries set in Act 13**

Problems with Magnitude, Alignment in the Major Risks We Studied in Detail

- **Fee ranges from \$5K to \$60K per well per year**
 - Road damages alone may be \$5.4K - \$23K [*do not cite or quote, analysis in review*], although damages drop off after first year
 - **Emissions damages are \$4K - \$18K, with up to 80% persisting beyond sunset of fee collection**
- **Fee revenue accrues directly to drilling counties only, with some revenue to state**
 - Statewide agencies (PennDOT, PA DEP) may not be fully compensated for costs
 - **Some damages (e.g., air emissions) are a regional issue**

Air Emissions Are a Cost of Shale Gas Extraction But Can Be Reduced

- **Under current practices, emissions from diesel and natural gas combustion are guaranteed**
- **Long-term emissions dominate, with most not at the shale-extraction site and not related to “unconventional” nature of resource**
- **Changes in regulatory framework may be appropriate**
 - **Improvements in technology can reduce emissions (e.g., green completions)**
 - **Aggregation may or may not make sense**
- **Uncertainty in estimates is high, further study is warranted**

Epilogue

- **RAND paper published in *ERL* on January 31, 2013**
- **Jan 31: PA DEP releases revised GP-5 General Operating Permit for NG compression/processing facilities**
- **Jan 31: PA DEP inventory presentation, dated Feb 14, is leaked**
- **Feb 12: PA DEP officially releases unconventional drilling industry inventory**
- **Feb 20: EPA's Office of Inspector General's report on improving air emissions data for oil and gas sectors**
- **Feb 21: Webinar on GP-5 and inventory**



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