RFF's Center for Energy Economics and Policy

The Environmental Risks of Shale Gas Development

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Director, Center for Energy Economics and Policy

Shale Gas Forum, Beijing, sponsored by CSEP
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Overview

- A brief overview of RFF' shale gas project
- A survey of experts' assessments of key environmental risks
- A statistical study of shale gas/water quality study
- Global warming potential of shale gas (fugitive methane)

Risk Matrix

Site Development and Drilling Preparation
After locating a site for shale gas development, the area must be excavated and prepared for drilling. Preparation activity also often includes leveling of the site.

Activity	Intermediate Impacts					
	Groundwater	Surface Water	Soil Quality	Air Quality	Habitat Disruption	Community Disruption
Clearing of land/construction of roads, well pads, pipelines, other infrastructure		Stormwater flows Invasive species	Stormwater flows	Conventional air pollutants and CO_2	Habitat fragmentation Invasive species	Industrial landscape Light pollution Noise pollution
On-road vehicle activity		Stormwater flows		Conventional air pollutants and CO_2	Other	Noise pollution Road congestion/accidents
Off-road vehicle activity		Stormwater flows		Conventional air pollutants and CO_2	Other	Noise pollution

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Drilling Activities
Drilling begins by boring a single well shaft vertically into the desired formation. One or more lateral wells are then drilled from the end of the vertical wellbore, angling to run horizontally through the shale formation.

Activity	Intermediate Impacts					
	Groundwater	Surface Water	Soil Quality	Air Quality	Habitat Disruption	Community Disruption
Drilling equipment operation at surface	Drilling fluids/cuttings	Drilling fluids/cuttings	Drilling fluids/cuttings	Conventional air pollutants and CO_2		Industrial landscape Light pollution Noise pollution
Drilling of vertical and lateral wellbore	Methane Drilling fluids/cuttings Intrusion of saline-formation water into fresh groundwater	Drilling fluids/cuttings		Methane		

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1. Expert survey of shale gas development risks

2. Statistical analysis:
a) Effects of shale gas activity on surface water quality in Pennsylvania
b) Effects of shale gas activity on residential property values

3. Regulatory/ industry practices baseline, including state-by-state regulatory analysis

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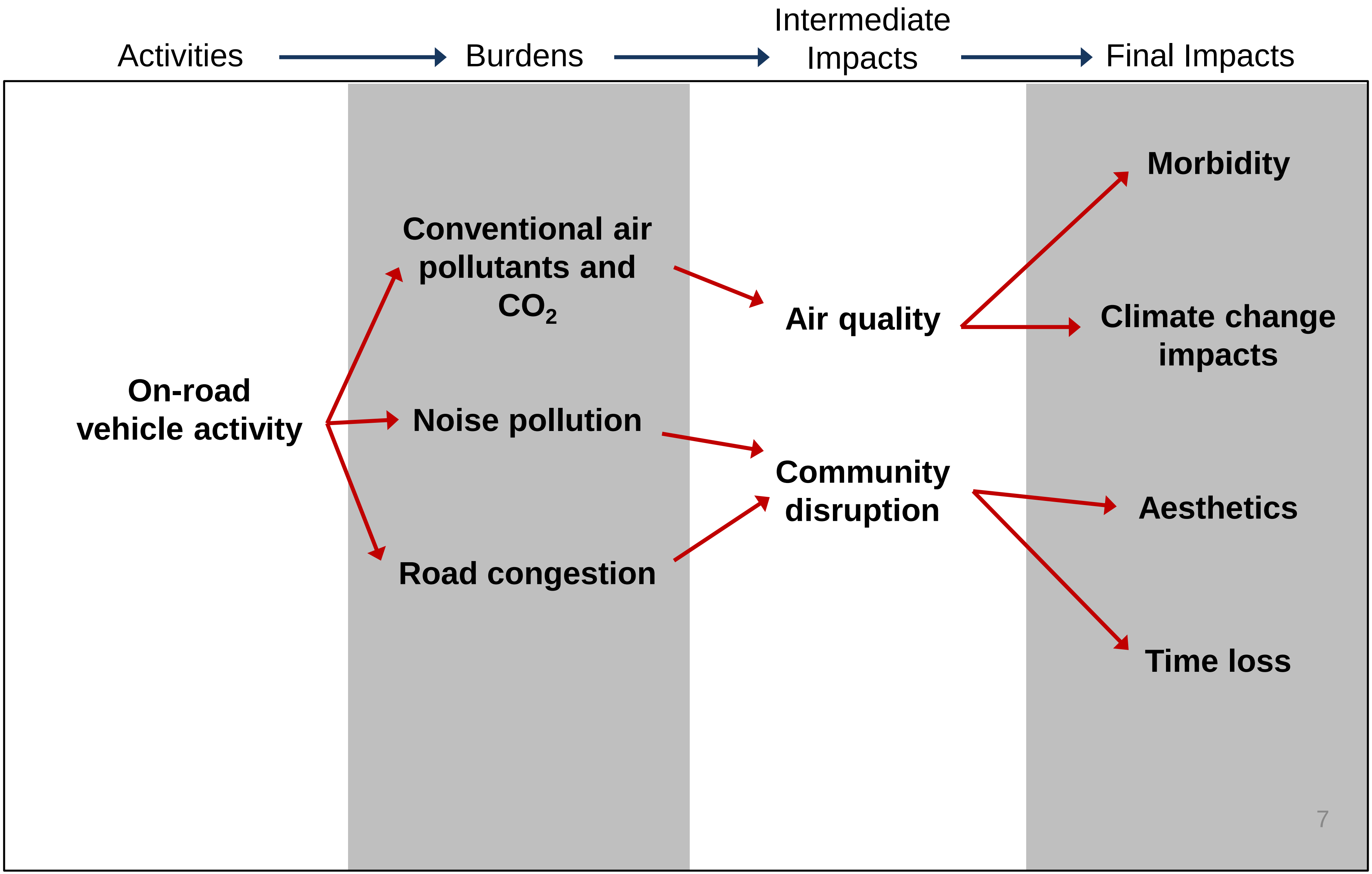
Creating Impact Pathways (Risk Matrices on the web)

Activities	Burdens	Intermediate Impacts	Final Impacts
Site development and drilling preparation	**Air pollutants**	**Groundwater**	**Human health impacts**
Vertical drilling	**Drilling fluids and cuttings**	**Surface water**	**Market impacts**
Horizontal drilling	**Saline water intrusion**	**Soil quality**	**Ecosystem impacts**
Fracturing and completion	**Fracturing fluids**	**Air quality**	**Climate change impacts**
Well production and operation	**Flowback constituents (other than fracturing fluids)**	**Habitat disruption**	**Quality of life impacts**
Flowback and produced water storage/disposal	**Produced water constituents**	**Community disruption**	
Shutting-in, plugging and abandonment	**Condenser and dehydration additives**	**Occupational hazard**	
Workovers	**Habitat/community disruptions**		
Upstream and downstream activities	**Other**		

Creating Impact Pathways (cont.'d)



Who is included in Expert Survey

Confidentiality

- **NGOs (35)**: Most national environmental groups, some local
- **Academics (63)**: Universities/think tanks
- **Government (42)**: Key federal agencies; about half the relevant states; river basin commissions
- **Industry (75)**: Many operating and support companies, trade associations, consulting firms, law firms

Number of Routine Priorities

	Total	NGO	Industry	Academia	Government
10th Percentile	5	38	3	12	2
50th Percentile	39	100	28	42	27
90th Percentile	125	218	72	117	80
Mean	55	**105**	**39**	54	**40**
Observations	215	35	75	63	42

➔ NGO's are the outlier in number of high priorities identified

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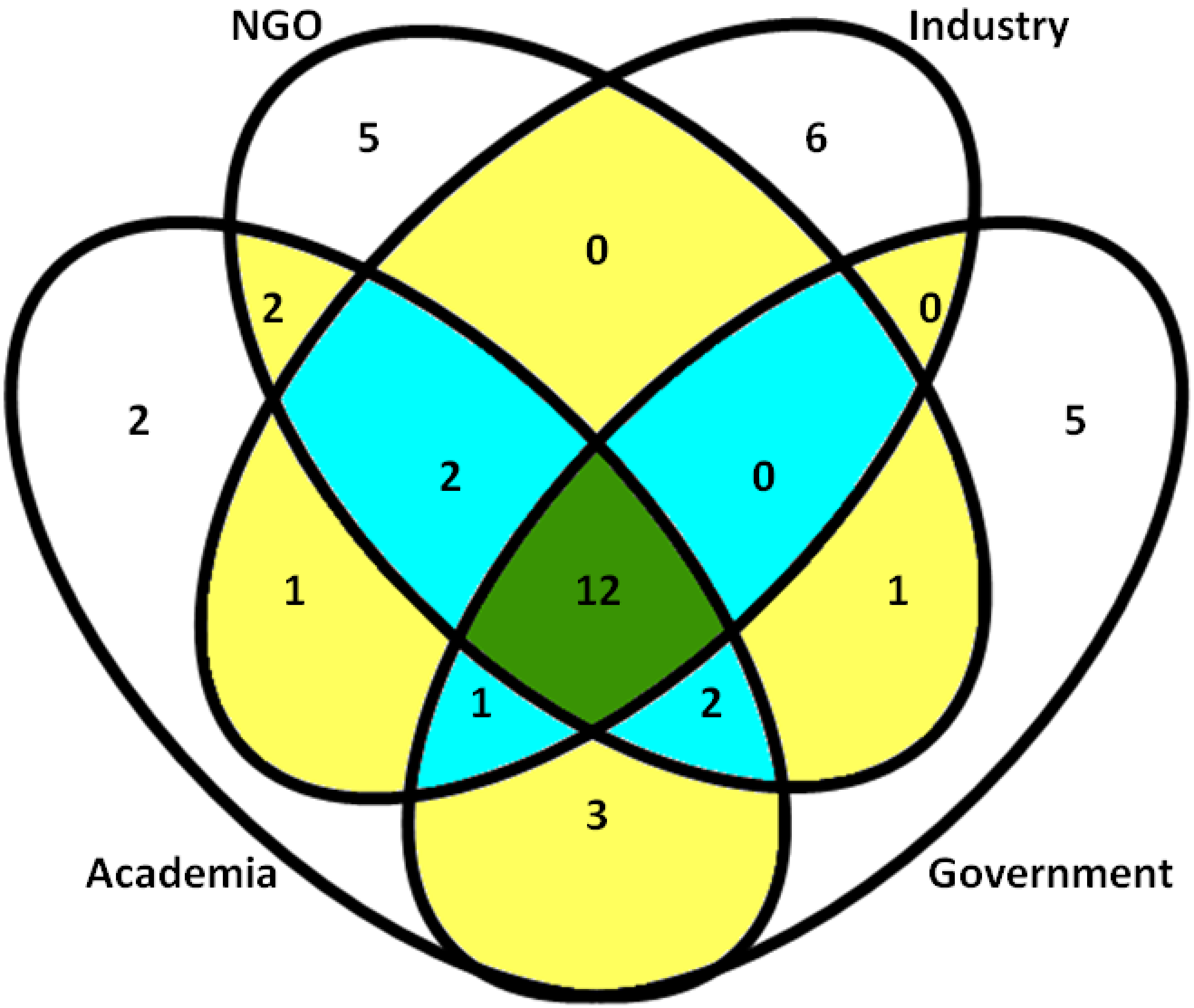
NGO
Industry
5
6
0
2
0
2
5
2
0
1
12
1
1
2
3
Academia
Government

Activities	Intermediate Impacts					Totals*
Site Development and Drilling Preparation	**Groundwater**	**Surface water**	**Air Quality**	**Habitat disruption**	**Community Disruption**	2-0-0-2 / 18
Clearing of land/construction of roads, well pads, pipelines, other infrastructure		Stormwater flows (4)		Habitat fragmentation (12)	Industrial landscape (A) (34)	2-0-0-1 / 9
On-road vehicle activity					Road congestion (I) (16)	0-0-0-1 / 5
Drilling Activities	**Groundwater**	**Surface water**	**Air Quality**	**Habitat disruption**	**Community Disruption**	1-2-3-7 / 45
Drilling equipment operation at surface	Drilling fluids and cuttings (G) (55)	Drilling fluids and cuttings (A,G) (32)			Noise pollution (I) (30)	0-0-1-2 / 7
Drilling of vertical and lateral wellbore	Intrusion of saline-formation water (G) (27)					0-0-0-1 / 5
Casing and cementing	Methane (I,A,G) (8) Intrusion of saline-formation water (I) (32)					0-1-0-1 / 6
On-road and off-road vehicle activity					Road congestion (I) (24)	0-0-0-1 / 5
Use of surface water and groundwater	Freshwater withdrawals (A) (25)	Freshwater withdrawals (N) (20)				0-0-0-2 / 5
Venting of methane			Methane (12)			1-0-0-0 / 2
Storage of drilling fluids at surface		Drilling fluids and cuttings (A,G) (23)				0-0-1-0 / 6
Disposal of drilling fluids, drill solids, cuttings	Drilling fluids and cuttings (N,A) (18)	Drilling fluids and cuttings (N,I,A) (14)				0-1-1-0 / 5
Fracturing and Completion	**Groundwater**	**Surface water**	**Air Quality**	**Habitat disruption**	**Community Disruption**	4-1-1-2 / 62
Use of surface water and groundwater	Freshwater withdrawals (6)	Freshwater withdrawals (5)				2-0-0-0 / 5
Flowback of reservoir fluids	Flowback & produced water constituents (N,A) (20)	Flowback & produced water constituents (N,I,A) (9)				0-1-1-0 / 11
Venting of methane			Methane (9)			1-0-0-0 / 2
Storage of fracturing fluids at drill site	Fracturing fluids (G) (36)	Fracturing fluids (15)				1-0-0-1 / 6
On-road and off-road vehicle activity					Road congestion (I) (36)	0-0-0-1 / 7
Well Production/Operation	**Groundwater**	**Surface water**	**Air Quality**	**Habitat disruption**	**Community Disruption**	0-1-0-3 / 21
Well Production	Flowback & produced water constituents (N) (29)	Flowback & produced water constituents (N,A,G) (18)				0-1-0-1 / 7
Condensate tank, dehydration unit operation			Volatile organic compounds (N) (58)			0-0-0-1 / 7
Compressor operation			Conventional air pollutants & CO_2 (N) (41)			0-0-0-1 / 3
Fracturing Fluids, Flowback, and Produced Water Storage and Disposal	**Groundwater**	**Surface water**	**Air Quality**	**Habitat disruption**	**Community Disruption**	5-1-2-4 / 80
On-site pit or pond storage	Flowback and produced water constituents (2) Fracturing fluids (G) (25)	Flowback and produced water constituents (1) Fracturing fluids (7)	Volatile organic compounds (N) (41)			3-0-0-2 / 11
Transport off-site					Road congestion (I) (27)	0-0-0-1 / 13
Treatment, release by industrial wastewater treatment plants		Flowback and produced water constituents (9)				1-0-0-0 / 6
Treatment, release by municipal wastewater treatment plants		Flowback and produced water constituents (2) Fracturing fluids (A,G) (20)				1-0-1-0 / 6
Deep underground injection	Flowback & produced water constituents (G) (45)				Seismic vibrations (I,A) (30)	0-0-1-1 / 6
Application of wastewater for road de-icing, dust suppression		Flowback & produced water constituents (N,A,G) (17)				0-1-0-0 / 11
Totals*	2-1-2-8 / 52	7-4-3-1 / 53	2-0-0-3 / 53	1-0-0-0 / 31	0-0-1-6/48	12-5-6-18 / 264

*Totals are: 4 agree - 3 agree - 2 agree - 1 agree / total pathways

**Activities that have no pathways selected in any group's top 20 are omitted. No soil quality pathways were selected, no other activity pathways were selected.

Key: Four in agreement | Three in agreement | Two in agreement | One in agreement

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Top consensus categories (out of top 20)

7 surface water: 3 fracking fluids, 3 flowback, 1 run-off

2 groundwater: on-site flowback storage, water withdrawals

2 air quality: methane venting

1 habitat: fragmentation from site development and pipelines

Industry priority for community impacts

Not from “fracking” per se

Not soil impacts

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Accident Priorities

All groups share the top two accident priorities: cement failure and casing failure

All but industry identify impoundment failure as #3

Industry identifies truck accidents.

Government

Probability	Very Low	Low	Medium	High	Very High	Total
<0.1	13 7.7%	6 3.6%	6 3.6%	4 2.4%	7 4.2%	36 21.4%
0.1-1	7 4.2%	12 7.1%	15 8.9%	16 9.5%	4 2.4%	54 32.1%
1-2%	2 1.2%	14 8.3%	11 6.5%	4 2.4%	3 1.8%	34 20.2%
3-5%	0 0.0%	2 1.2%	11 6.5%	4 2.4%	2 1.2%	19 11.3%
6-10%	1 0.6%	0 0.0%	6 3.6%	0 0.0%	2 1.2%	9 5.4%
11-15%	0 0.0%	0 0.0%	5 3.0%	2 1.2%	3 1.8%	10 6.0%
26-50%	0 0.0%	0 0.0%	0 0.0%	3 1.8%	0 0.0%	3 1.8%
>50%	0 0.0%	0 0.0%	2 1.2%	1 0.6%	0 0.0%	3 1.8%
Total	23 13.7%	34 20.2%	56 33.3%	34 20.2%	21 12.5%	168 100.0%

Academics

Probability	Very Low	Low	Medium	High	Very High	Total
<0.1	4 1.5%	19 7.1%	27 10.1%	27 10.1%	21 7.8%	98 36.6%
0.1-1	1 0.4%	12 4.5%	33 12.3%	18 6.7%	3 1.1%	67 25.0%
1-2%	1 0.4%	3 1.1%	13 4.9%	17 6.3%	7 2.6%	41 15.3%
3-5%	0 0.0%	6 2.2%	8 3.0%	12 4.5%	2 0.7%	28 10.4%
6-10%	1 0.4%	2 0.7%	15 5.6%	4 1.5%	0 0.0%	22 8.2%
11-15%	0 0.0%	0 0.0%	1 0.4%	3 1.1%	1 0.4%	5 1.9%
26-50%	0 0.0%	0 0.0%	0 0.0%	1 0.4%	1 0.4%	2 0.7%
>50%	0 0.0%	0 0.0%	3 1.1%	1 0.4%	1 0.4%	5 1.9%
Total	7 2.6%	42 15.7%	100 37.3%	83 31.0%	36 13.4%	268 100.0%

NGOs

Probability	Very Low	Low	Medium	High	Very High	Total
<0.1	0	0	7	3	6	16
	0.0%	0.0%	3.8%	1.6%	3.2%	8.6%
0.1-1	0	1	10	11	9	31
	0.0%	0.5%	5.4%	5.9%	4.8%	16.7%
1-2%	0	2	14	18	5	39
	0.0%	1.1%	7.5%	9.7%	2.7%	21.0%
3-5%	0	2	17	20	3	42
	0.0%	1.1%	9.1%	10.8%	1.6%	22.6%
6-10%	0	1	5	5	10	21
	0.0%	0.5%	2.7%	2.7%	5.4%	11.3%
11-15%	0	1	6	3	1	11
	0.0%	0.5%	3.2%	1.6%	0.5%	5.9%
26-50%	0	0	2	12	6	20
	0.0%	0.0%	1.1%	6.5%	3.2%	10.8%
>50%	0	0	1	0	5	6
	0.0%	0.0%	0.5%	0.0%	2.7%	3.2%
Total	0	7	62	72	45	186
	0.0%	3.8%	33.3%	38.7%	24.2%	100.0%

Industry

Probability	Very Low	Low	Medium	High	Very High	Total
<0.1	10 3.8%	9 3.4%	24 9.2%	23 8.8%	12 4.6%	78 29.8%
0.1-1	9 3.4%	17 6.5%	19 7.3%	25 9.5%	11 4.2%	81 30.9%
1-2%	1 0.4%	9 3.4%	13 5.0%	8 3.1%	4 1.5%	35 13.4%
3-5%	0 0.0%	6 2.3%	12 4.6%	8 3.1%	2 0.8%	28 10.7%
6-10%	1 0.4%	5 1.9%	7 2.7%	4 1.5%	3 1.1%	20 7.6%
11-15%	0 0.0%	0 0.0%	2 0.8%	4 1.5%	1 0.4%	7 2.7%
26-50%	1 0.4%	0 0.0%	1 0.4%	4 1.5%	4 1.5%	10 3.8%
>50%	0 0.0%	1 0.4%	1 0.4%	1 0.4%	0 0.0%	3 1.1%
Total	22 8.4%	47 17.9%	79 30.2%	77 29.4%	37 14.1%	262 100.0%

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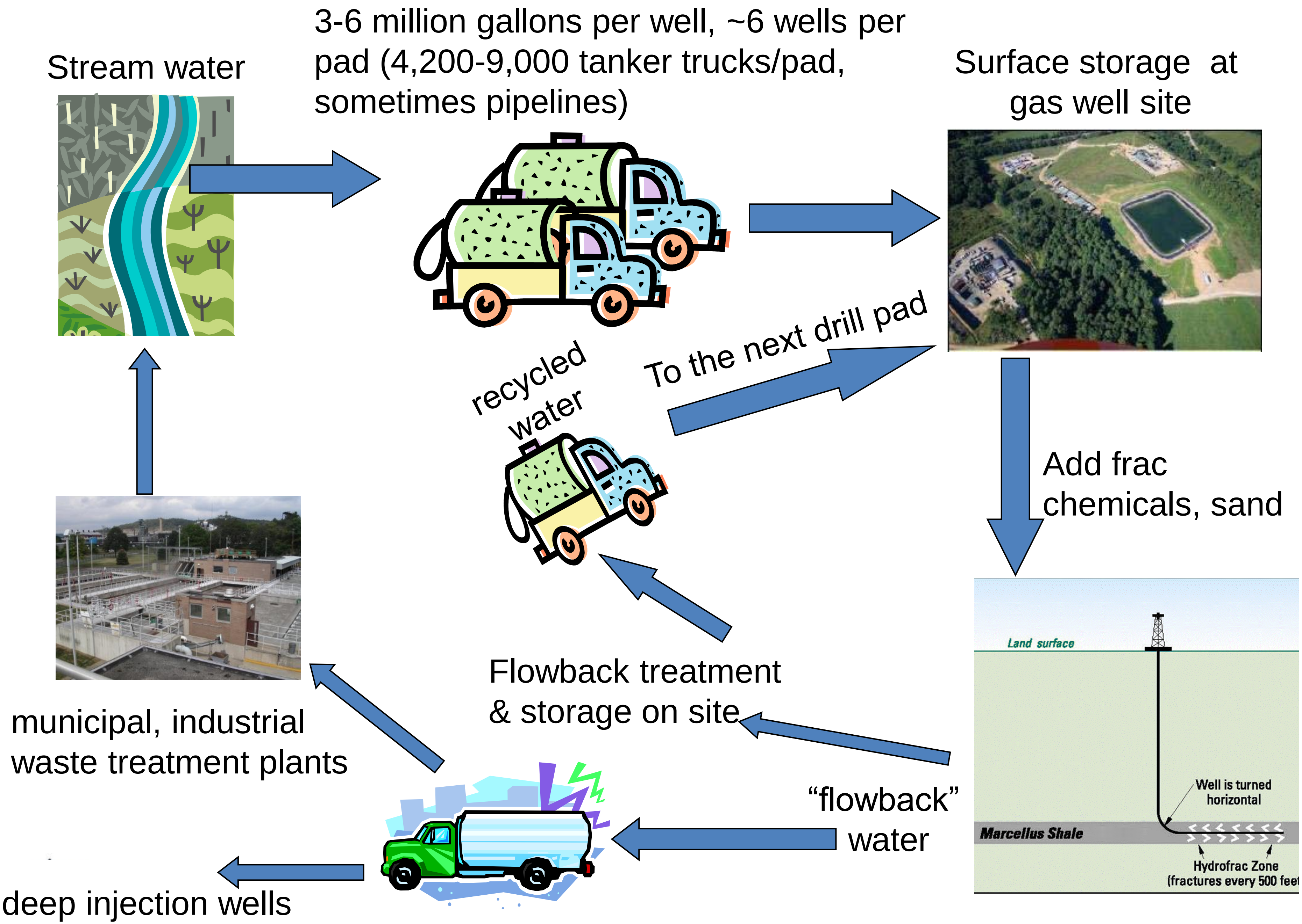
Fluids priorities

Of top 10, 6 are in common

- NORMs
- Oils
- Aromatic hydrocarbons
- H_2S


Stream water
3-6 million gallons per well, ~6 wells per pad (4,200-9,000 tanker trucks/pad, sometimes pipelines)
Surface storage at gas well site
recycled water
To the next drill pad
Add frac chemicals, sand
Land surface
Well is turned horizontal
Marcellus Shale
Hydrofrac Zone
(fractures every 500 feet
Flowback treatment & storage on site
municipal, industrial waste treatment plants
"flowback" water
deep injection wells

Research design for shale gas/water quality study

- Uses regression analysis to estimate relationships between:

  - The location/timing of shale gas wells; and
  - The location/timing of shale gas waste treatment by municipal and industrial treatment facilities.

  and

  - Chloride and TSS concentrations in rivers and streams:

- Uses large sets of dummy variables to capture variation over time and space in all other sources of chloride and TSS.

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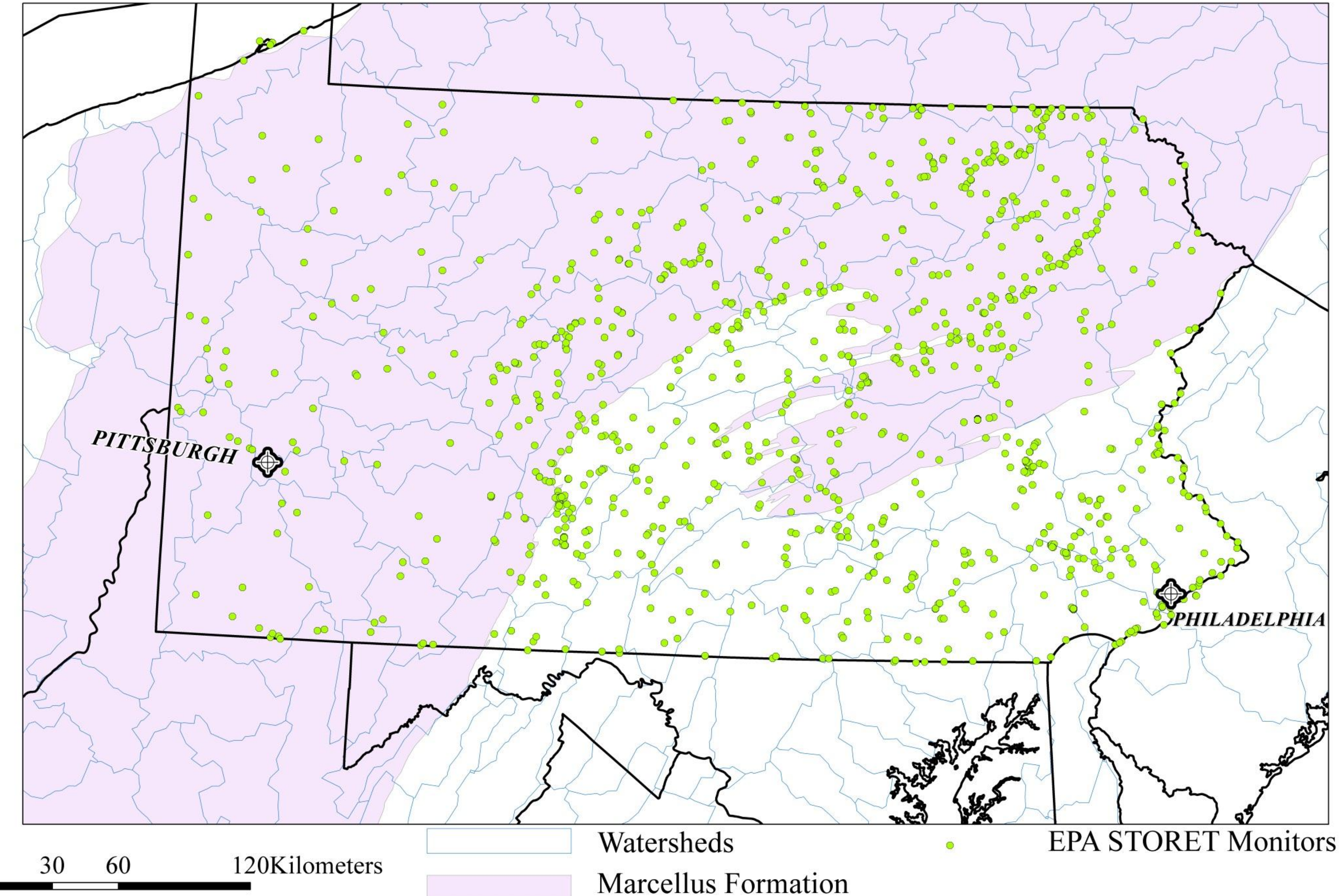
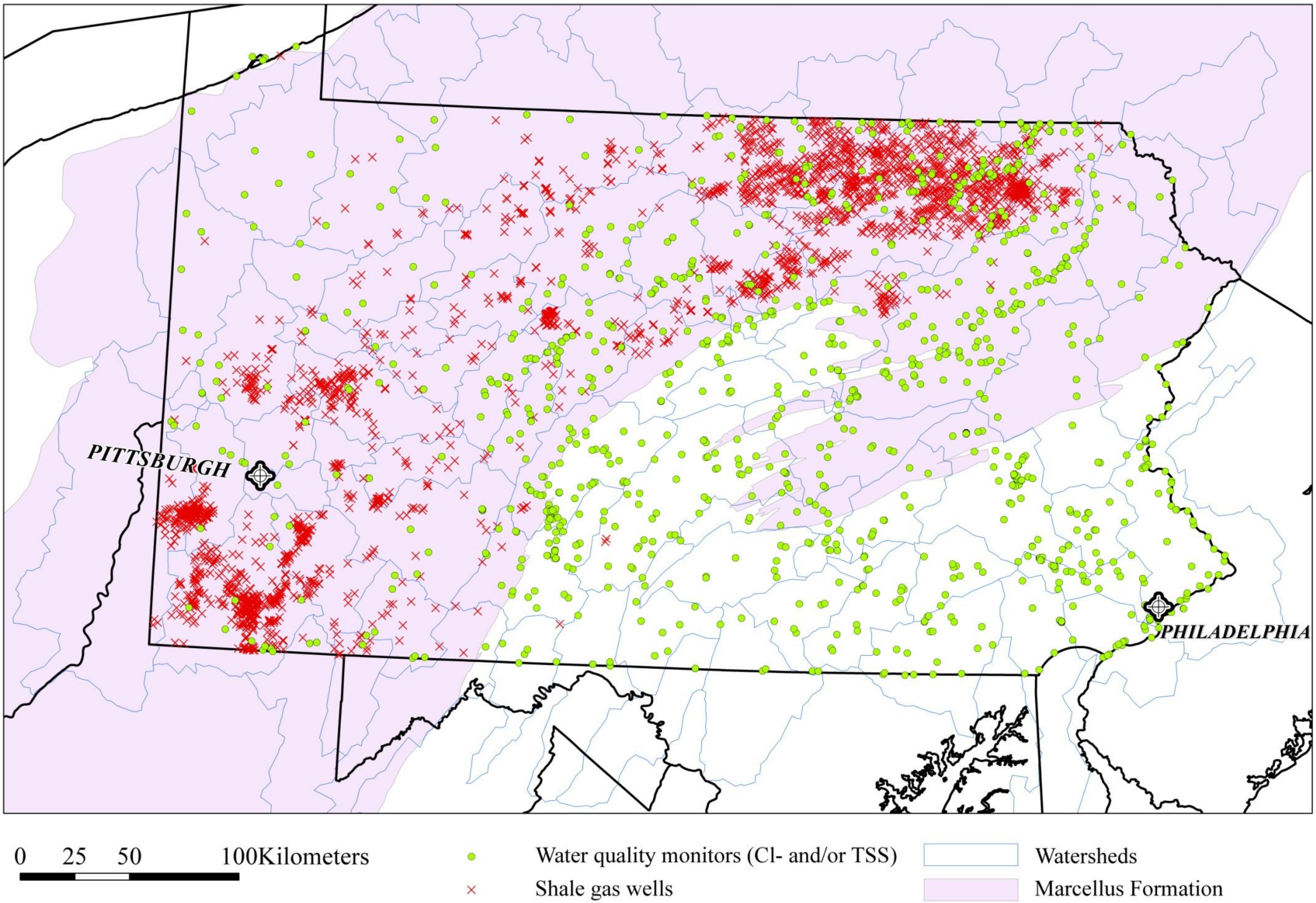
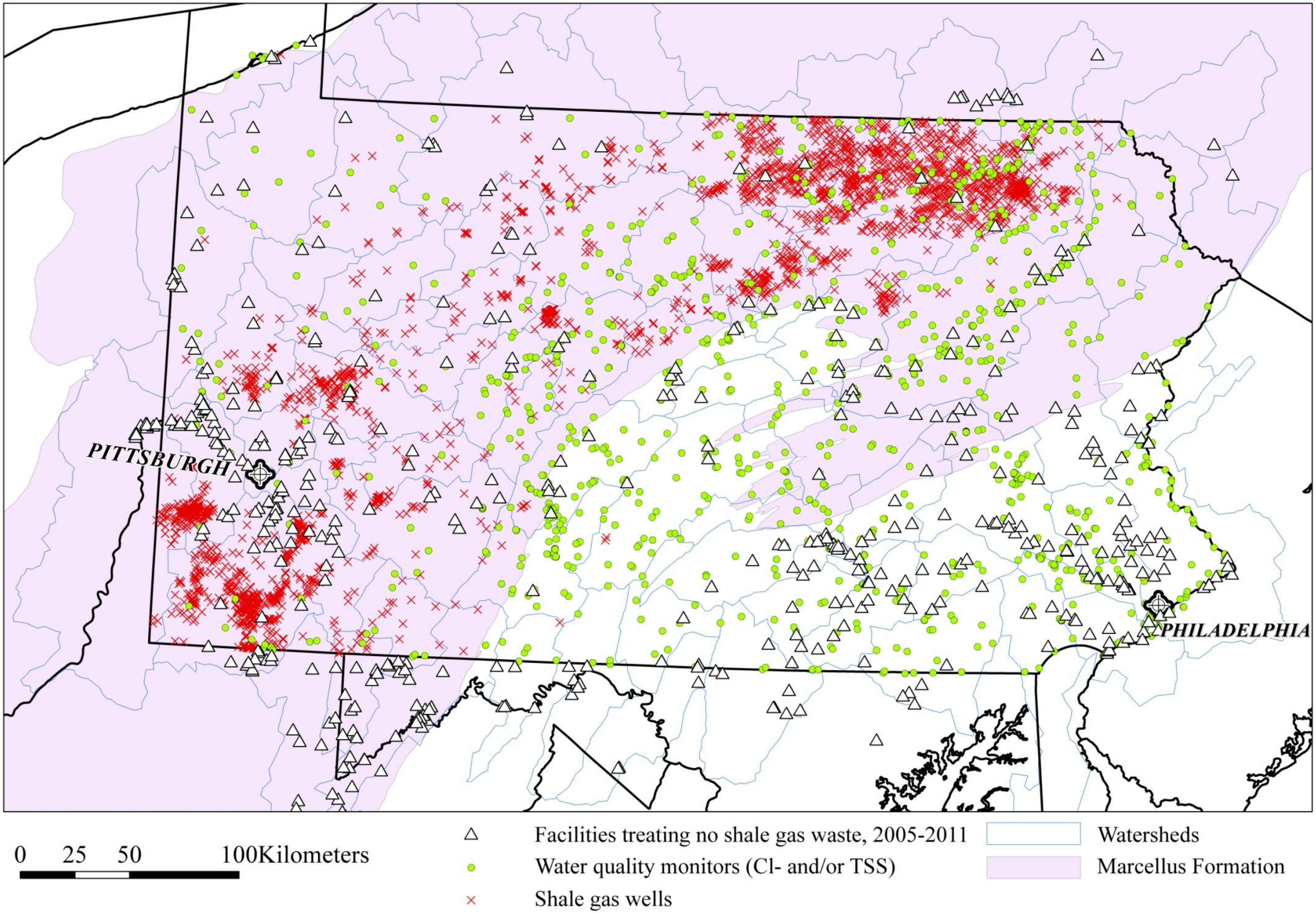
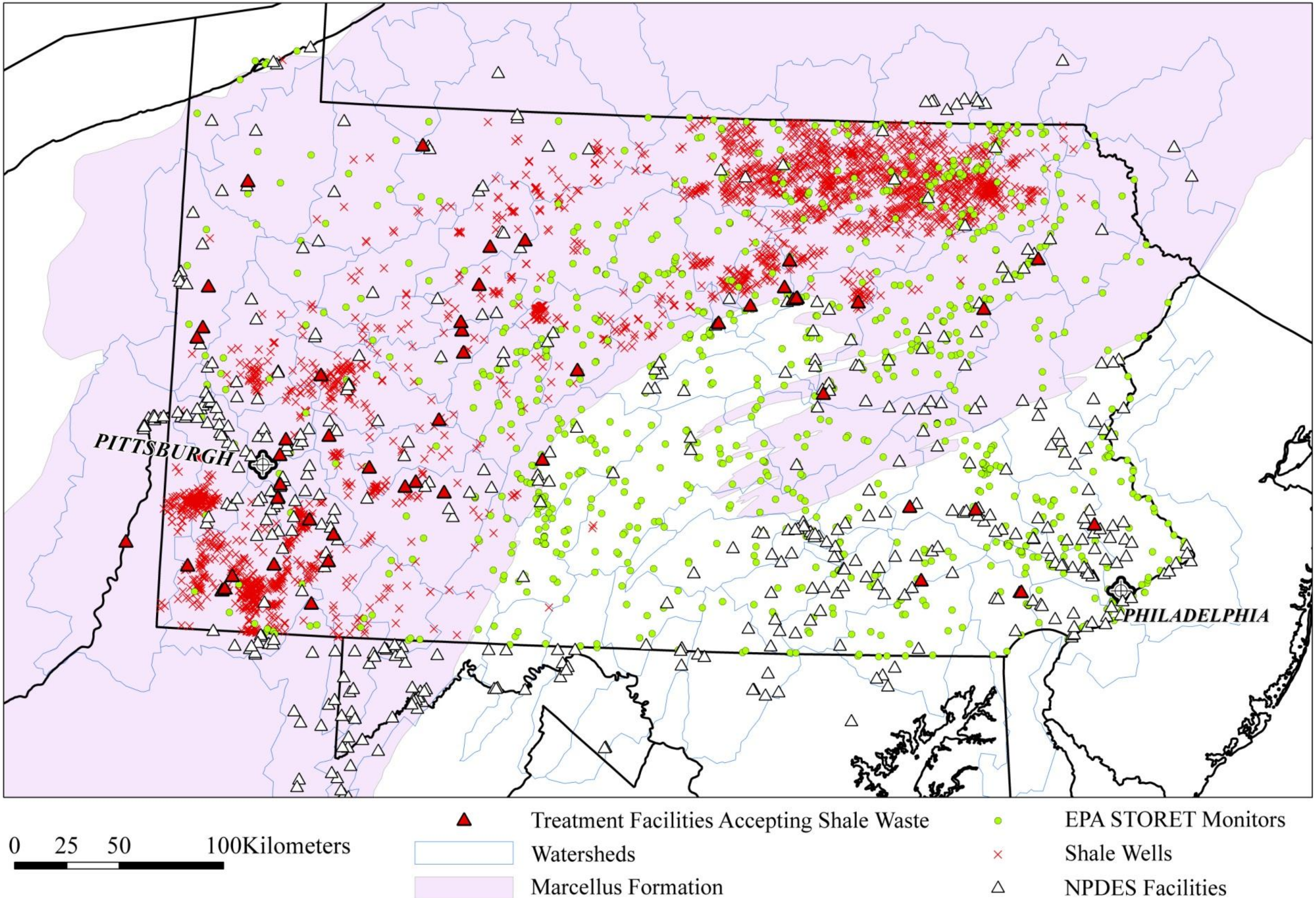

PITTSBURGH
PHILADELPHIA
Watersheds
Marcellus Formation
EPA STORET Monitors
30
60
120Kilometers


PITTSBURGH
PHILADELPHIA
0 25 50 100Kilometers
Water quality monitors (Cl- and/or TSS)
Shale gas wells
Watersheds
Marcellus Formation

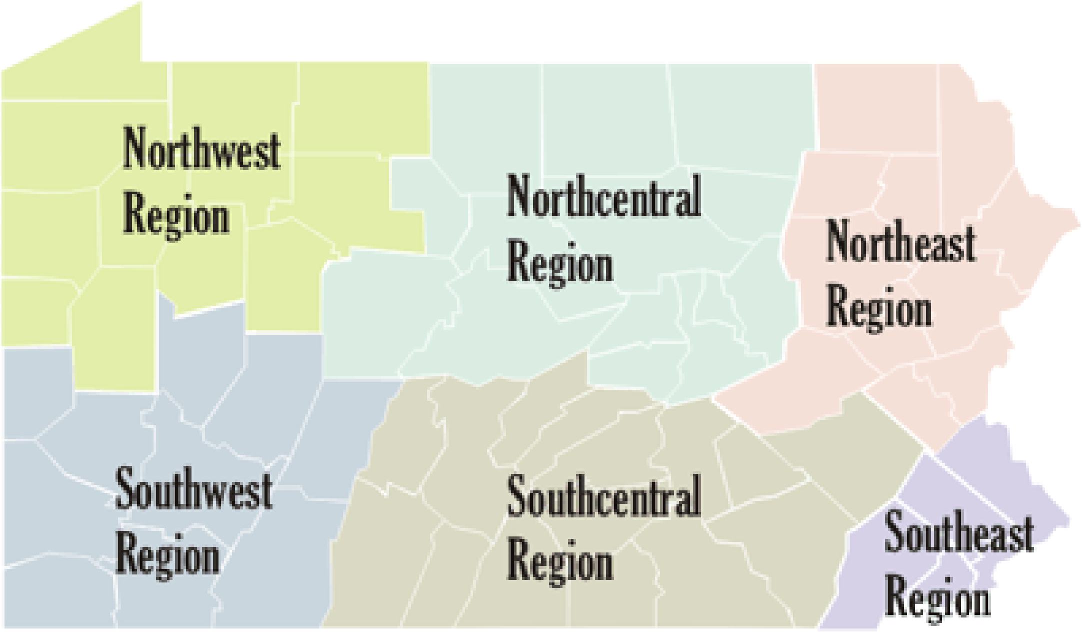


PITTSBURGH
PHILADELPHIA
0 25 50 100Kilometers
Facilities treating no shale gas waste, 2005-2011
Water quality monitors (Cl- and/or TSS)
Shale gas wells
Watersheds
Marcellus Formation



PITTSBURGH
PHILADELPHIA
0 25 50 100Kilometers
Treatment Facilities Accepting Shale Waste
Watersheds
Marcellus Formation
EPA STORET Monitors
Shale Wells
NPDES Facilities

Chloride (mg/l) from waste samples in PA, as reported to DEP (Form 26R)



PA DEP region	Obs	Mean	St dev	Min	Max
N Central - Williamsport	191	35561.53	67462.3	0.59	320000
SW - Pittsburgh	80	54001.16	44971.50	18.5	192000
NW & NE	62	35687.72	66768.47	1.0	350000

Preliminary results from analysis of Form26R waste analysis reports, PA DEP.

Chloride in shale gas waste may be correlated with other contaminants

- Form 26 lab samples tested for many contaminants; some are correlated with chloride (pre-treatment).
- Treatment facilities in PA may be removing these correlated contaminants with treatment processes.

Contaminant	Obs.	Corr. with Cl
Chloride	333	1.00
Bromide	193	0.49
Arsenic	26	0.03
Barium	87	0.38
Cadmium	16	0.92
Strontium	55	0.87
Gross Alpha	135	0.22
Gross Beta	137	0.12
Radium 228	133	0.20

Preliminary results from analysis of Form26R waste analysis reports, PA DEP.

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Preliminary results

- **Chloride** results:
  - No statistically significant impact of shale gas **wells** on downstream Cl^- concentrations.
    - Positive result would have been consistent with large-scale contamination from accidental releases, etc.
  - Release of treated shale gas **waste** to surface water increases downstream Cl^- concentrations.
- **TSS** results:
  - An increase in the upstream density of shale gas **wells** raises downstream TSS concentrations.
  - No statistically significant impact of shale gas **waste** treatment on downstream TSS concentrations.

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An Important Caveat

- Our findings on Chloride and TSS are for the U.S. only

- These findings do **NOT** imply that shale gas development in China will have the same impact on water quality
  - China's environmental regulations and enforcement are different from those in the U.S., so firm behavior may differ in the two counties.
  - China's availability and quality of water resources may also differ

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Is shale gas low in global warming potential?

Is natural gas (from shale) a lower carbon substitute for coal?

- Fugitive methane*GWP + other fuel cycle elements < > Coal emissions (CO_2e)
- Fugitives need to be < 3% of production

Will natural gas substitute for coal in the power sector?

Issues with fugitive methane

- Flared vs. vented
- Fugitive methane as costly loss vs. costs to capture
- Appropriate GWP (20, 100, 500 years)
- Assumptions about EUR over time
- Misinterpretations/disputes about data
- Metering errors confounding loss estimates

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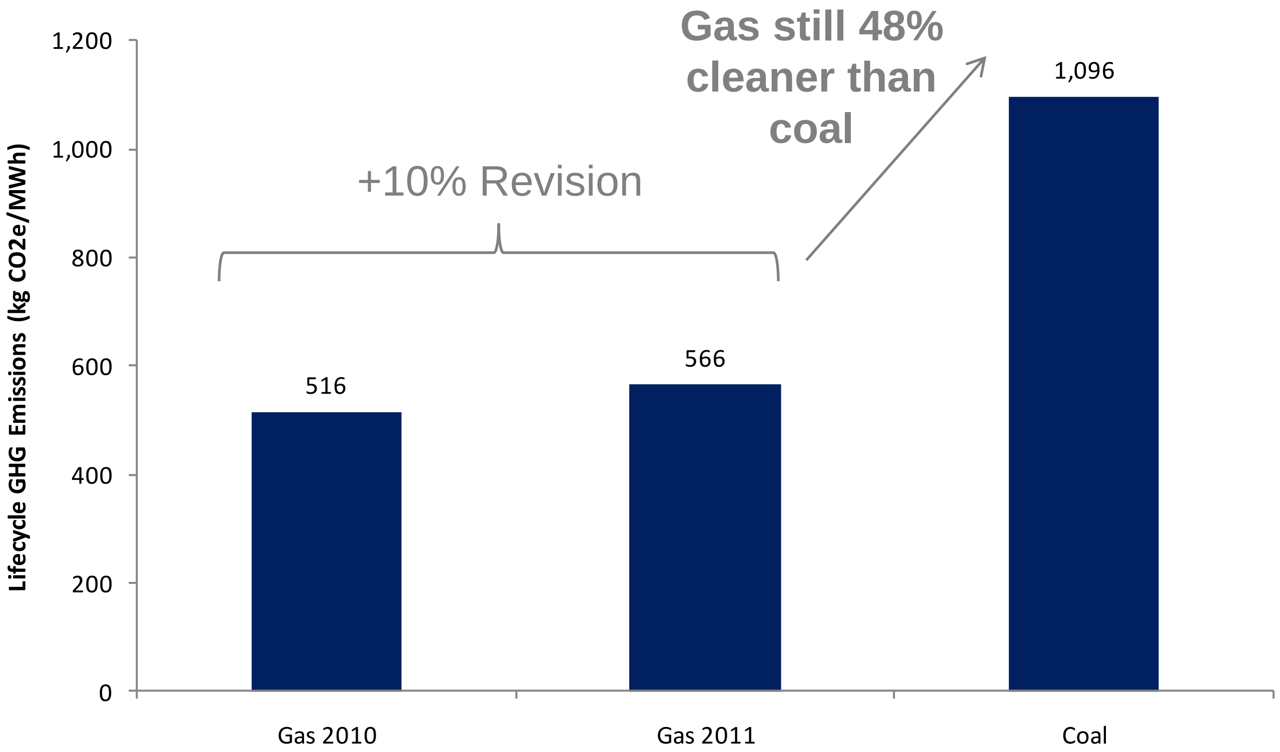
EIA-ICF (2011) Lifecycle CO_2e Analysis Shows Gas (with fracking): 50% Cleaner than Coal



Note: 100 year global warming potential
Source: EIA, ICF International, DBCCA analysis 2011

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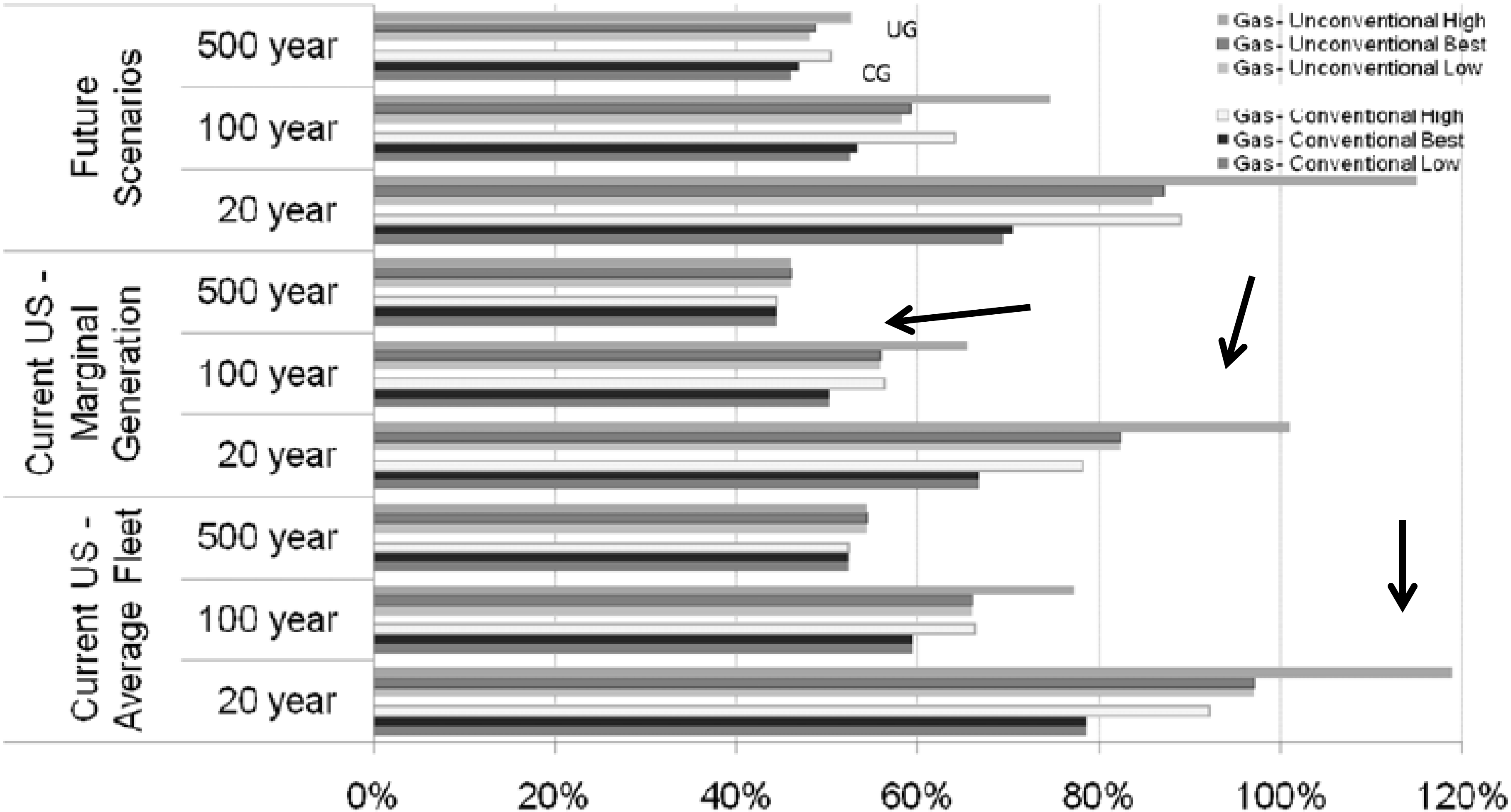
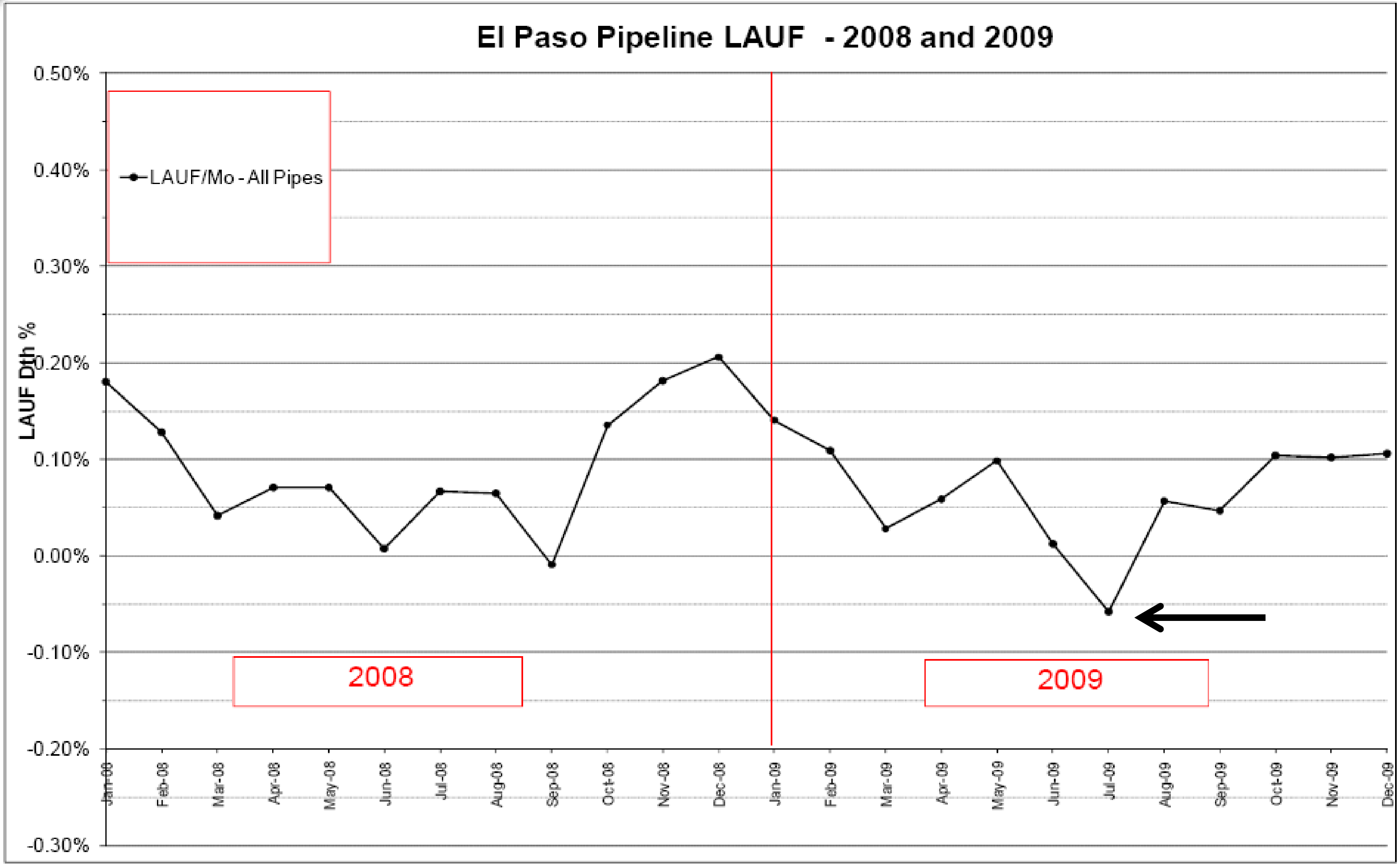


Nathan Hultman, Dylan Rebois, Michael Scholten and Christopher Ramig, 2011. The greenhouse impact of unconventional gas for electricity generation Environ.. Res. Lettl, 6, 044008

And Why LAUF Should Not Be Used as Proxy for GHG Emissions



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Towards resolution

- New API study shows methane venting from gas production is 50% lower than EPA estimates. Much of this from shale gas.
- EPA has authority to compel companies to provide fugitive methane data – due later this year
- Environmental Defense Fund and some O&Ps partnering to measure fugitive methane –report due next year

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Compare China with U.S.

Similarities

- Concern about air pollution
- Concern about global warming
- Water shortage, as in west Texas
- Topography? West Texas and Appalachia?

Differences

- Environmental impact depends on environmental regulation, which differs greatly between the two countries

Questions

- Any special seismicity concerns?
- Status of Surface Water quality in affected regions?
- Extent Ground Water is relied on for drinking
- Status of industry best practices?
- Awareness about green technologies?

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Thank You!

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