Prudent and Sustainable Water Management and Disposal Alternatives Applicable to Shale Gas Development

Author
J. Daniel Arthur, P.E., ALL Consulting

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Shale Gas History

- First Commercial Gas well – Fredonia, NY (1821)
  - New York's "Dunkirk Shale" at a depth of less than 30 feet
- Ohio Shale – Big Sandy Field (1880)
- Hydraulic Fracturing used in the Oil & Gas Industry (1950-60s)
- Barnett Shale – Ft. Worth Basin Development (1982)
- Horizontal wells in Ohio Shales (1980s)
- Successful Horizontal Drilling in Barnett Shale (2003)
- Horizontal Drilling Technology Applied in Appalachian Basin, Ohio and Marcellus Shales (2006)
- Horizontal Drilling and Hydraulic Fracturing are key technologies in the economic success of modern Shale Gas Development

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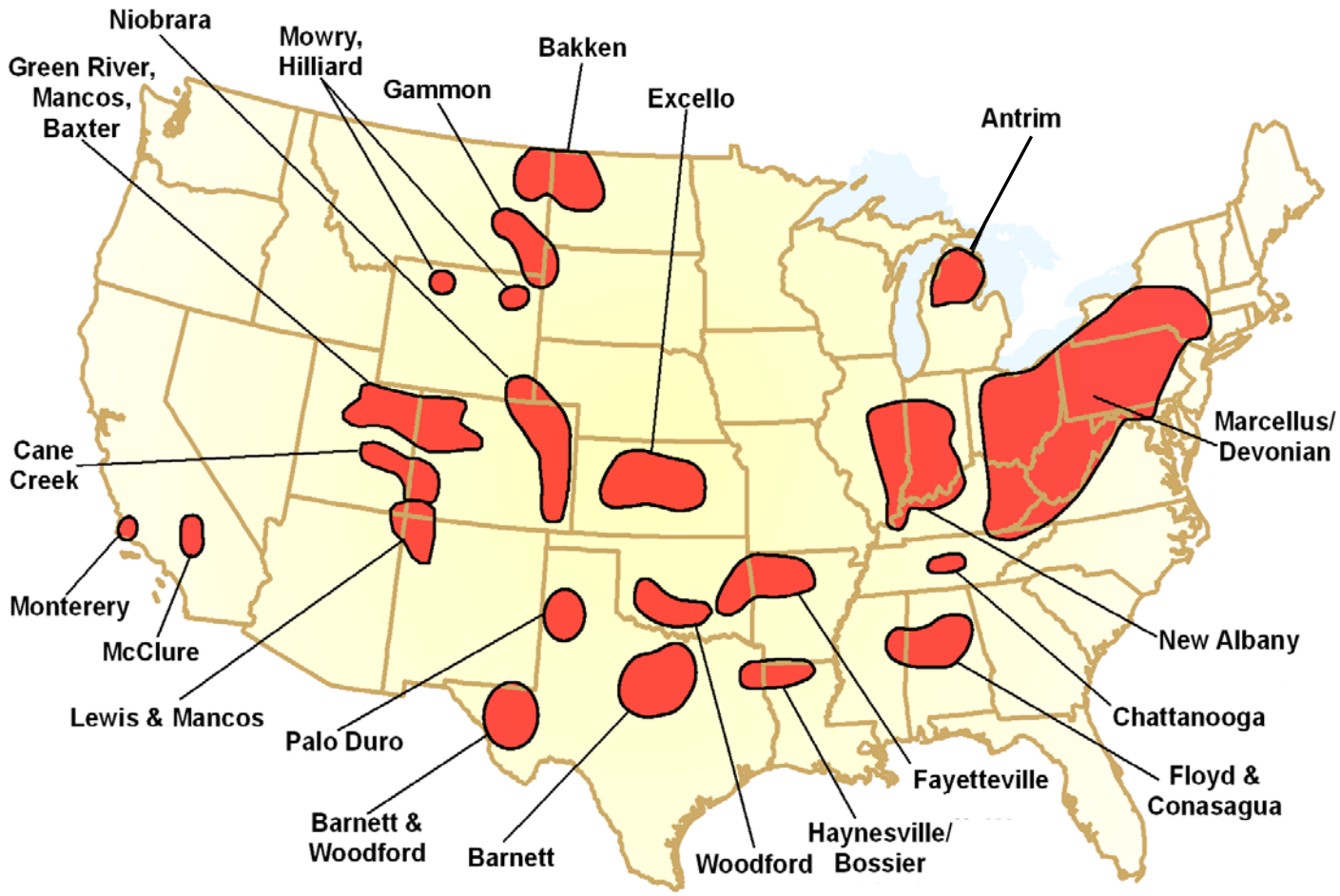
Shale Gas Basins of the U.S.



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Water Management Issues

Water Use

- The drilling and hydraulic fracturing of a horizontal shale gas well can require between 2 and 5 million gallons of water.
- Water supply in some areas can be challenging, particularly in the arid southwest. Even in areas with abundant water supplies, such as the Marcellus Shale development in the northeast, water supply can be a challenge due to public perception and opposition to oil and gas activities in general.
- Designing fracturing fluids that can use lower quality water such as higher TDS groundwater or municipal or industrial waste water.

Produced Water Treatment/Reuse or Disposal

- Initially, the water produced from a well contains a high percentage of the fracture fluid often referred to as flowback water. This consists primarily of the fresh water and very small percentages of chemicals which are used to make up the fracture fluid and some natural formation water. As production continues, the quality of this water changes to reflect more and more the natural formation water which is typically higher in TDS.
- Treatment options can be limited based on the TDS of the produced water as well as overall volumes requiring treatment.

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Water Use

- Primary water needs are for drilling fluids and hydraulic fracturing.
- Other water needs can include dust suppression and cleaning/flushing of the rig and equipment.
- Sources of water and water volumes needed vary from basin to basin.

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Shale Gas Water Use - 4 Major Shale Plays

- **Barnett Shale**
  10,000 BBLS used for Drilling
  70,000 BBLS used for Fracturing

  80,000 Total BBLS Used

  Assumed Wells per Year: 600
  Projected Total Water Use per Year:
  48 Million BBLS

- **Fayetteville Shale**
  1,500 BBLS used for Drilling
  70,000 BBLS used for Fracturing

  71,500 Total BBLS Used

  Assumed Wells per Year: 250
  Projected Water Use per Year:
  18 Million BBLS

- **Haynesville Shale**
  25,000 BBLS used for Drilling
  65,000 BBLS used for Fracturing

  90,000 Total BBLS Used

  Assumed Wells per Year: 200
  Projected Total Water Use per Year:
  18 Million BBLS

- **Marcellus Shale**
  2,000 BBLS used for Drilling
  90,000 BBLS used for Fracturing **

  92,000 Total BBLS Used

  Assumed Wells per Year: 600
  Projected Total Water Use per Year:
  55 Million BBLS

Shale Gas water use based on one operator's peak year projections. Other water use is an estimated average across entire shale play area.

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Total Water Use – 4 Major Shale Plays

Shale Play	Public Supply	Industrial and Mining	Power Generation	Irrigation	Livestock	Shale Gas	Total Water Use (Bbbl/yr)
Barnett	82.70%	4.50%	3.70%	6.30%	2.30%	0.40%	11.15
Fayetteville	2.30%	1.10%	33.30%	62.90%	0.30%	0.10%	31.9
Haynesville	45.90%	27.20%	13.50%	8.50%	4.00%	0.80%	2.15
Marcellus	11.97%	16.13%	71.70%	0.12%	0.01%	0.06%	85

Shale Gas water use based on one operator's peak year projections.

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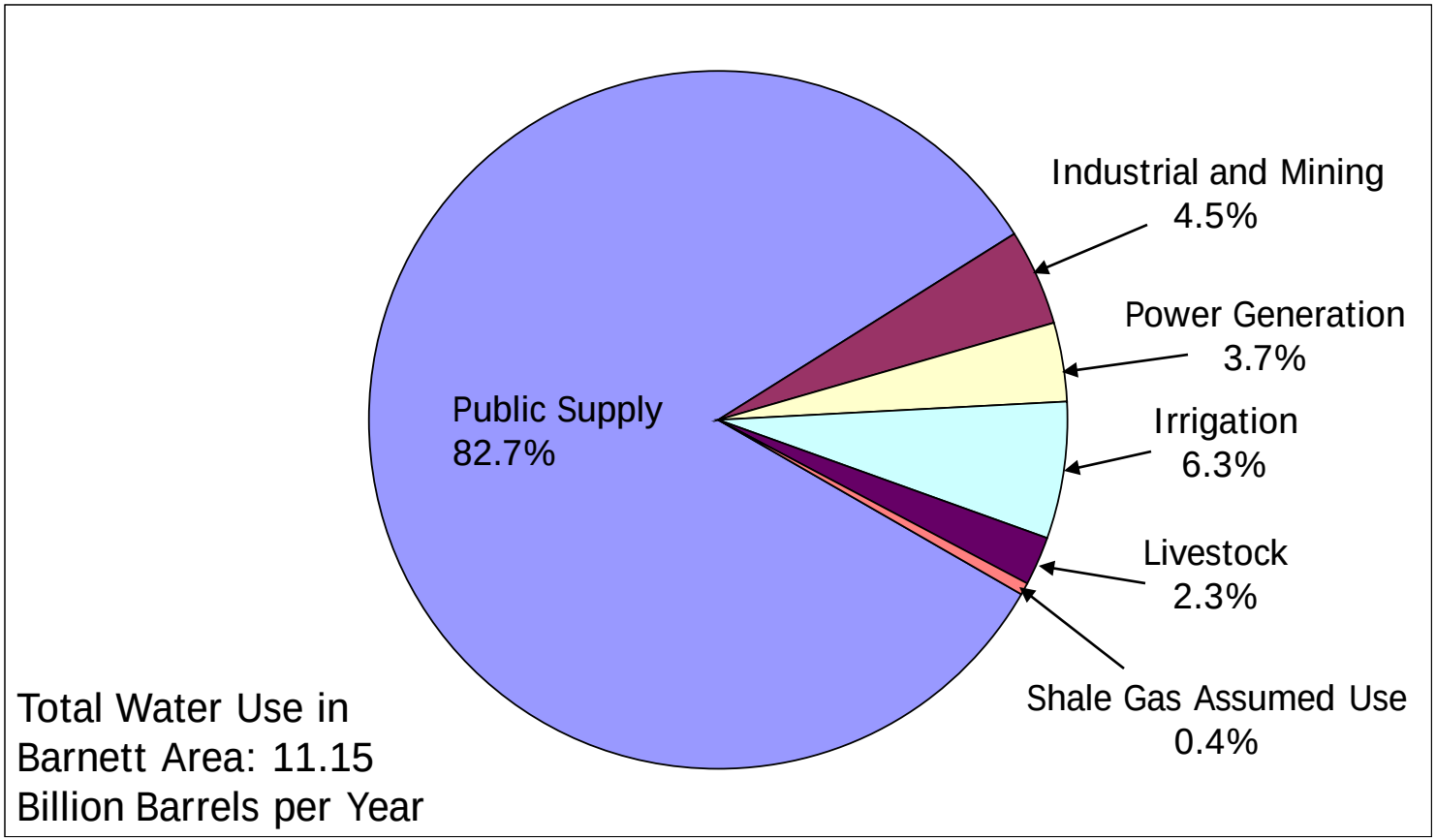
Water Use in Barnett Shale Area

Total Water Use (Surface Water and Ground Water) in North Central Texas (20 County Area) by Sector



Sources: 1) TWDB Water Use Database, 2006; 2) Shale Gas water use based on one operator's peak year projections.

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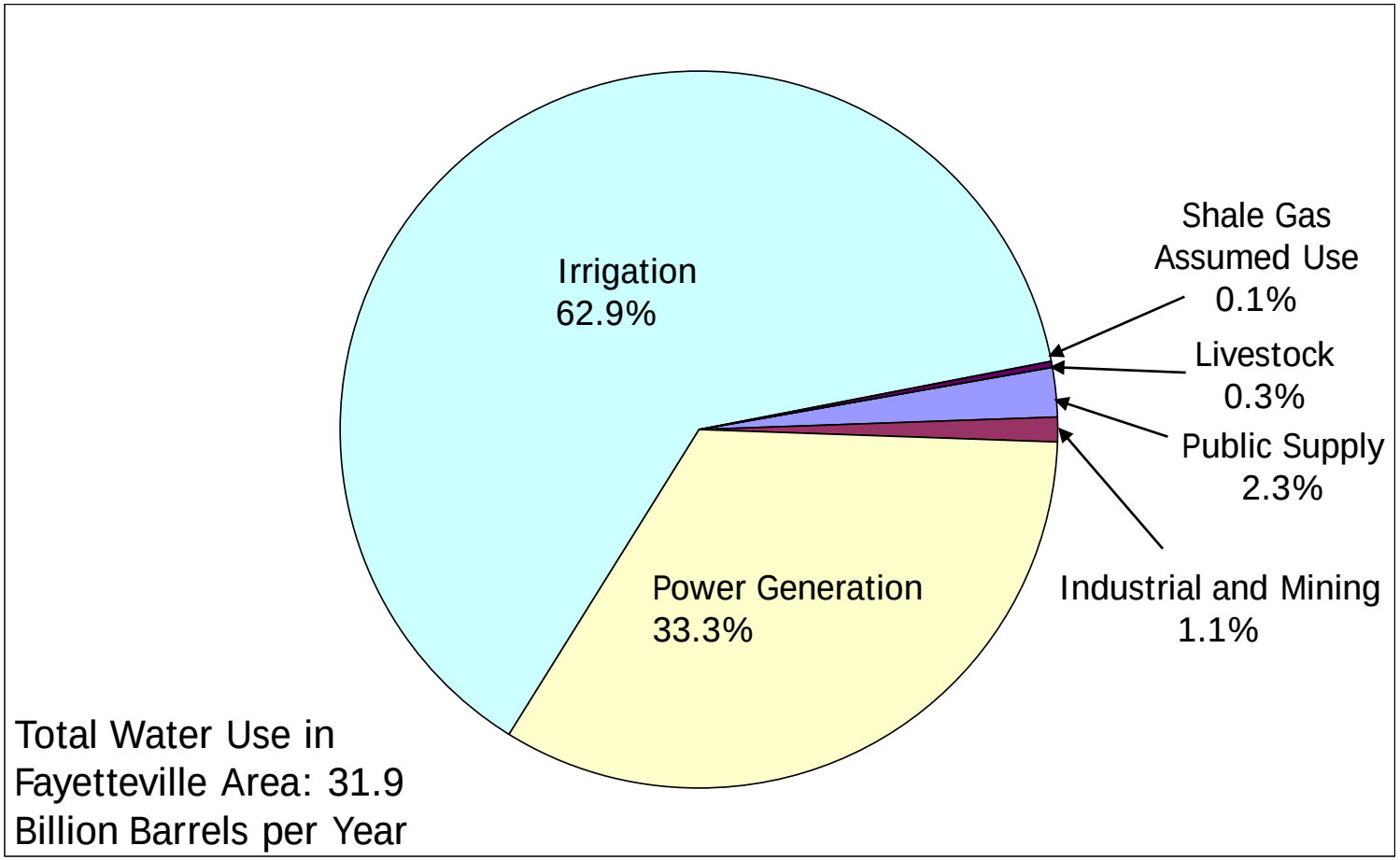
Water Use in Fayetteville Shale Area

Total Water Use (Surface Water and Ground Water) in Central Arkansas (19 County Area) by Sector



Sources: 1) USGS and Arkansas Natural Resources Commission, 2005; 2) Shale Gas water use based on one operator's peak year projections.

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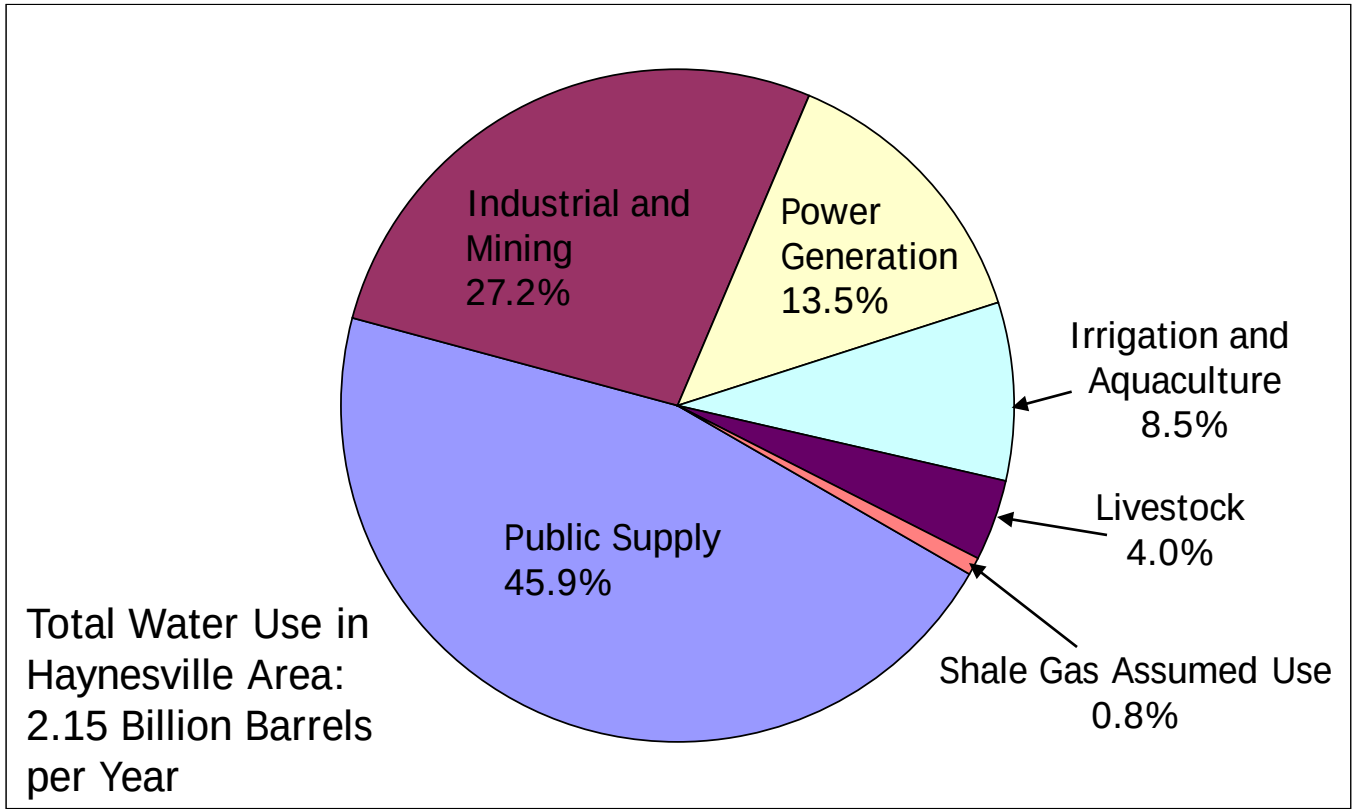
Water use in Haynesville Shale Area

NW Louisiana (8 Parish Area) and East Texas (6 County Area)
Total Water Use (Surface Water and Ground Water) by Sector



Sources: 1) USGS "Water Use in Louisiana, 2005", 2) TWDB Water Use Database, 2004; 3) Shale Gas water use based on one operator's peak year projections.

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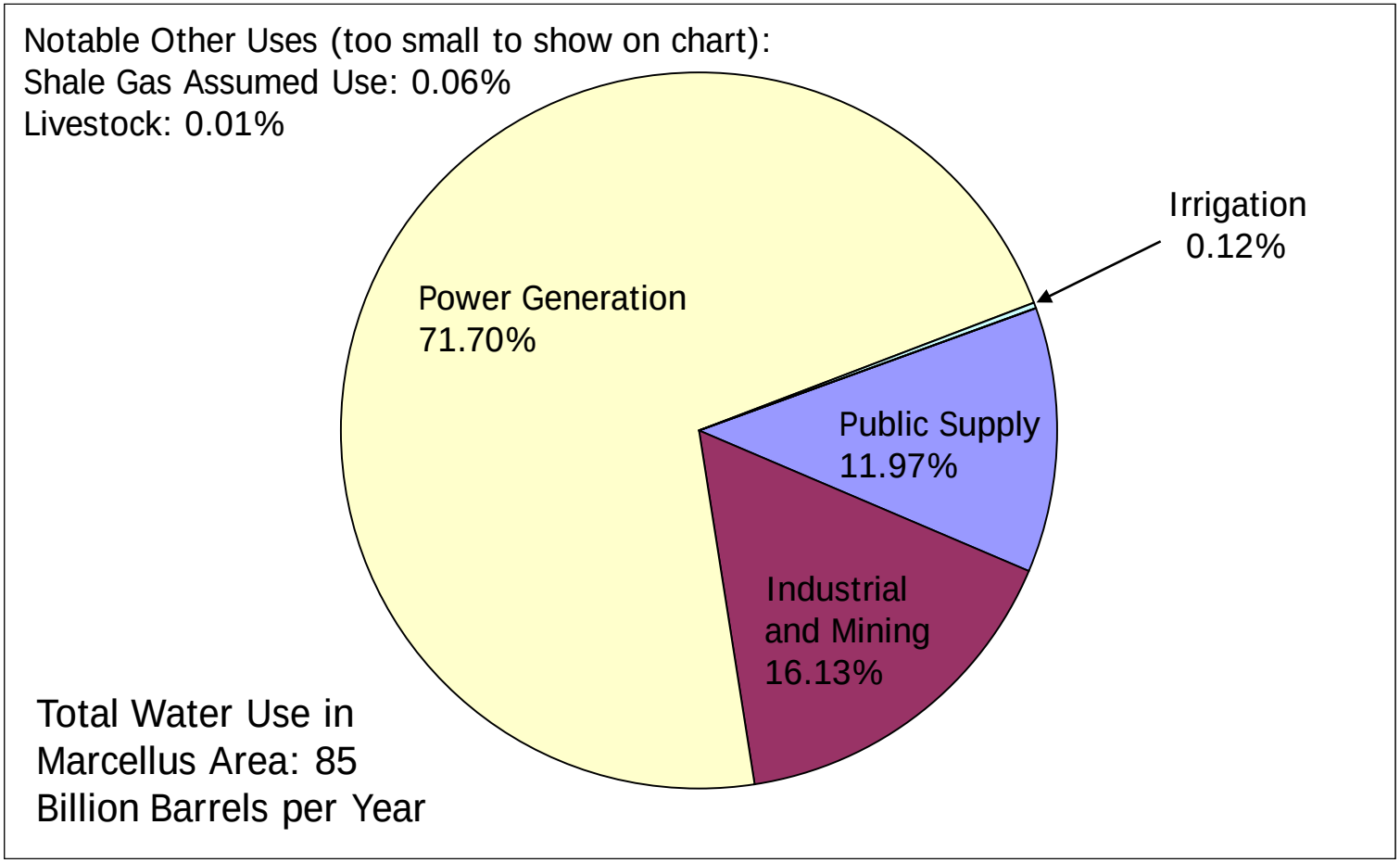
Water use in Marcellus Shale Area

Total Water Use (Surface Water and Ground Water) in Central PA (32 County Area), Southern NY (10 County Area), Northern WV (29 County Area), Western VA and MD (5 County Area), and Eastern OH (3 County Area) by Sector



Source: 1) USGS Estimated Use of Water in US, County Level Data for 2000; 2) Shale Gas water use based on one operator's peak year projections.

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Water Use for Energy

	Low	High
	gal / mmBTU	gal / mmBTU
Natural Gas	3	N/A
Synfuel - Coal Gasification	11	26
Tar Sands	15	38
Oil Shale	20	50
Synfuel - Fisher Tropsch	41	60
Coal	41	164
Hydrogen	143	243
Liquid Natural Gas	145	N/A
Petroleum / Oil - Electric Sector	1,200	2,420
Fuel Ethanol	2,510	29,100
Biodiesel	14,000	75,000

Source: Virginia Tech, 2008

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Water Sources

- **Surface water** is a primary source of water for drilling and hydraulic fracturing fluids.
- **Groundwater** is a potential source if surface water is not available. Groundwater availability is limited in some play areas such as the Marcellus where it typically consists of shallow alluvial aquifers less than 200 feet in depth.
- **Municipal water** suppliers can also be a source where available. In the Barnett Shale play area, the city of Ft. Worth and surrounding municipalities have supplied water for shale gas development.
- **Waste water** from municipal and industrial treatment facilities can be used depending on quality of the effluent and availability.
- **Produced water** can be treated and reused depending on the quality of the water; primarily the TDS and chloride concentrations. Typically, the effectiveness of a treatment system is less for water with a TDS above 20,000 ppm.

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Produced Water Treatment Options

- At present, economically viable options for the treatment of produced water consist primarily of Distillation/ Evaporation or Reverse Osmosis systems.
- All have limitations as to the quality and quantity of water that can be treated.
- Both produce a high concentration solute that requires disposal.
- Typically, as the TDS of the produced water increases, the quantity of useable water treated decreases. If the TDS of the produced water is 150,000 ppm, then only about 50% of the water treated would be useable…the remaining 50% would require disposal.

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Distillation/Evaporation

- Devon Energy is currently using a Distillation/Evaporation System in the Ft. Worth Barnett Shale Area.
- 2,500 BBL/day throughput with 2,000 BBL/day of Fresh Water produced.
- Requires approximately 100 MCF/day of Natural Gas to process the fluid.

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Distillation/Evaporation

- Chesapeake has plans to install four Water Evaporation Units at the Brentwood SWD Facility in Fort Worth.
- Employs natural process of evaporation to turn water into water vapor.
- Uses “Waste Heat” from compressor; no need to consume fuel.

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Reverse Osmosis

- Currently being Employed by EnCana in the Ft. Worth Barnett Shale Area.
- Uses a Reverse Osmosis Membrane System to remove salt from flow back water.
- 10,000 BBL/day Throughput with a Limit of 20,000 ppm Chlorides.
- Requires approximately 100 MCF/day of Natural Gas to process the fluid.

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Produced Water Disposal Options

- Primary means for management of produced water from Shale Gas is disposal in a Class II UIC well.
- Since Shale Gas development is occurring in areas that have not had oil and gas development in the past, Class II UIC wells may not be available.
- Other areas, such as the Marcellus Shale development area, are geologically challenged with regard to available injection zones. Currently there are only 6 disposal wells in NY and 8 in PA. Permitting a Class II well in NY may take a year or more.
- Other options include treatment at industrial or municipal treatment systems.

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Sustainable Development

- Sustainable Shale Gas Development will require a toolbox approach to both water supply and management issues.
- Multiple sources of water, including treatment and reuse of produced water and use of waste water, will need to be employed by industry to avoid conflicts with competing users…at least in some areas. Overall, the quantity of water needed for shale gas development is small as well as temporary compared to other long term uses such as power supply.
- Management and disposal of produced water may dictate the pace of shale gas development in some areas where options, such as available Class II UIC wells, are limited.

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Contact Information

J. Daniel Arthur, P.E.
darthur@all-llc.com
ALL Consulting
1718 S. Cheyenne Avenue
Tulsa, Oklahoma 74119

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