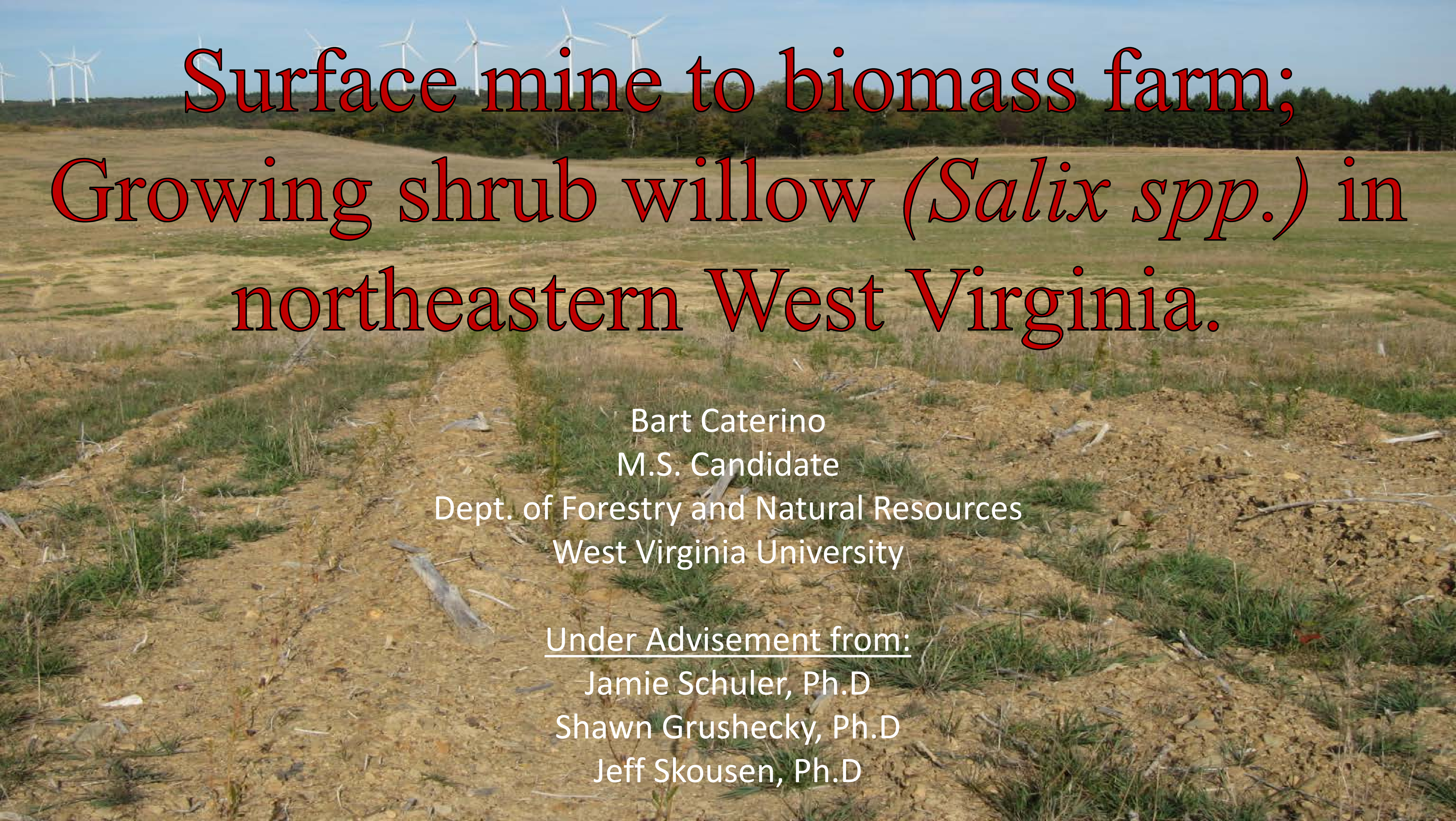

Surface mine to biomass farm; Growing shrub willow *(Salix spp.)* in northeastern West Virginia.

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Premise

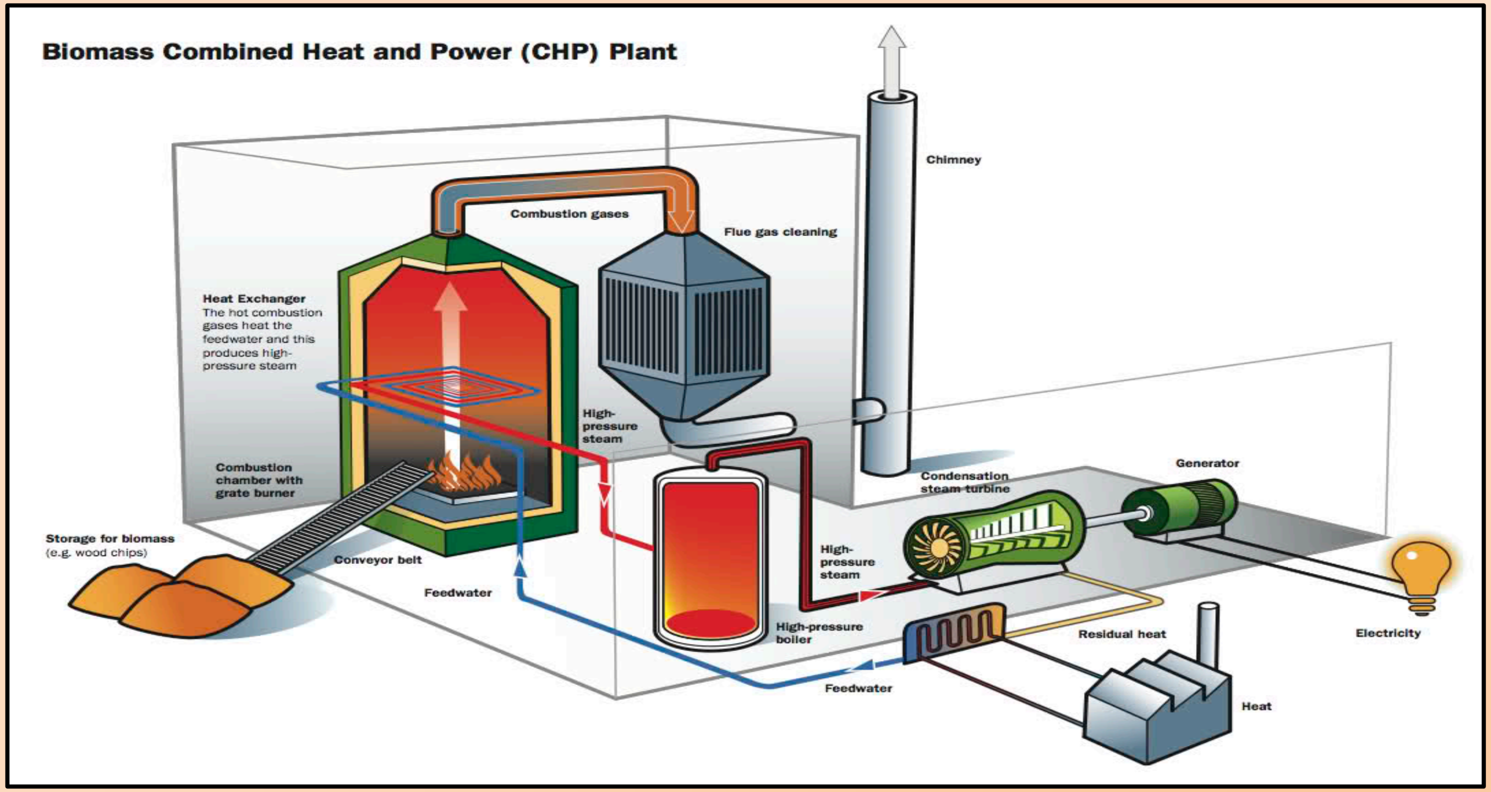
- West Virginia contains over 22,500 ha of surface mined land available for biomass plantation development (Maxwell et al. 2012)
- Woody biomass systems offer mine operators a method to achieve bond release
- Produce salable wood fiber
- Short harvest cycle relative to timber

Benefits

- Environment
  - Develops mine soil structure & fertility
  - Neutral net CO_2 emissions (Volk et al. 2006)
  - Co-firing reduces NO_x, SO_x, and Hg emissions
- Society
  - Diversify energy sector
  - Create employment
  - Reduce use of agricultural land for growing biomass

Technologies – Co-firing

Coal-wood mix for co-firing (source: *Biomass Magazine* "Biomass and Coal: A Powerful Combination")



Bio-firing power plant schematic. (source: Elnet Instal Electric Co.)

Technologies - Gasification

Auburn University’s mobile biomass gasifier.

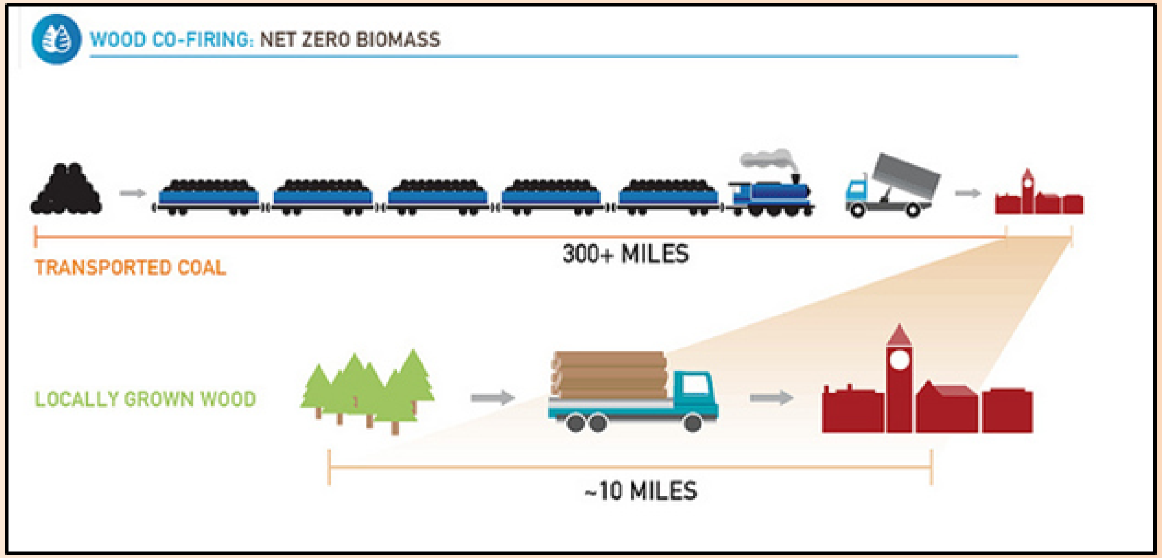
Emissions Reductions

Willow firing emissions and global warming potential (Keolian and Volk, 2005).

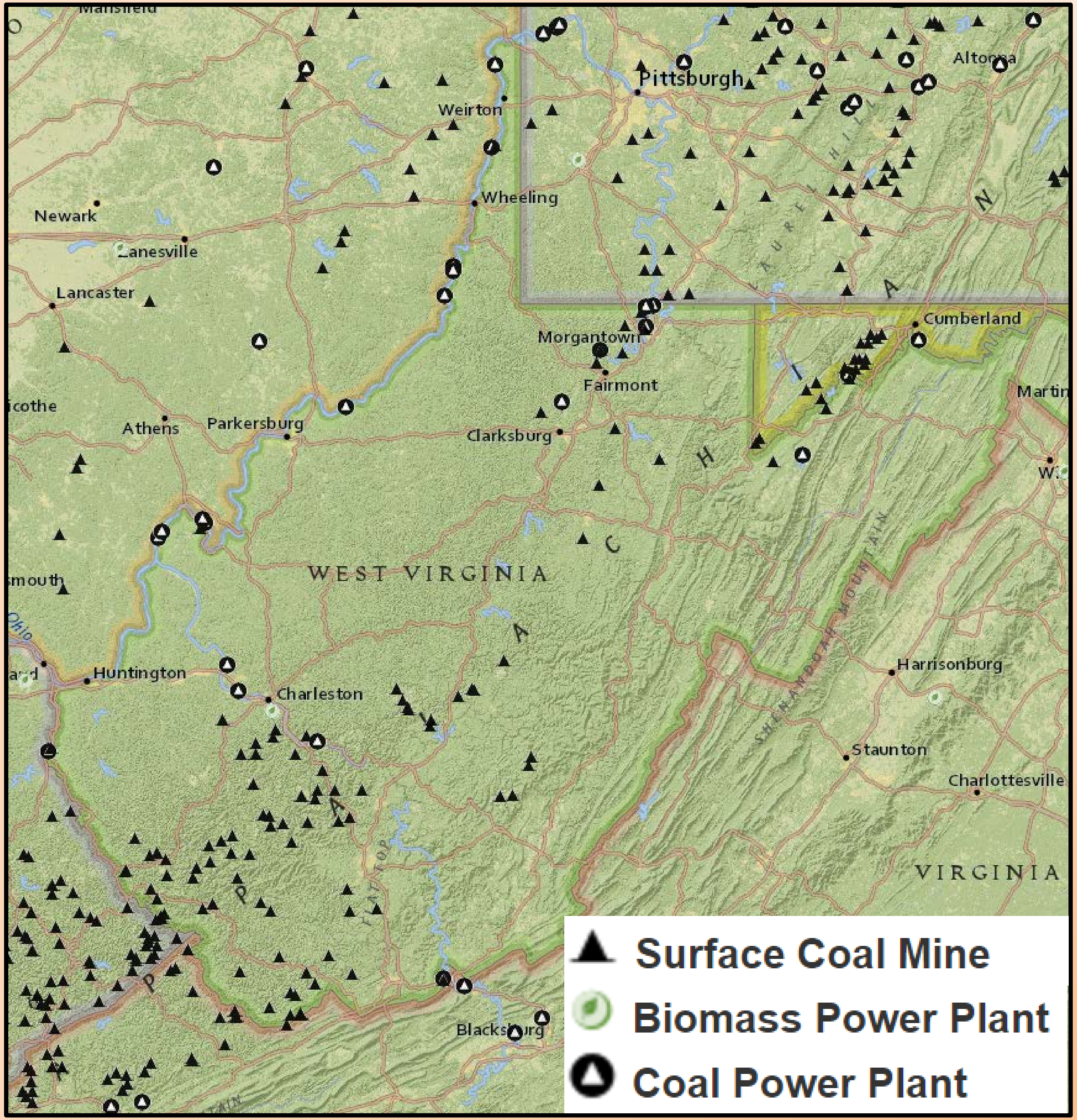
	CO (g CO/ MWh_{elec})	NO_x (g NO_2/ MWh_{elec})	SO_2 (g SO_2/ MWh_{elec})	Non-methane hydrocarbons (g/ MWh_{elec})	Particulates (unspecified size) (g/ MWh_{elec})	Global warming potential (kg CO_2 eq./ MWh_{elec})	Net energy ratio
10% co-fire, residue & willow blend[a]	152.4 (−3.2%)	1868 (9.7%)	13670 (−9.6%)	84.1 (−10.1%)[b]	707.6 (−6.3%)	905.7 (−7.4%)	0.341
10% co-fire, all willow[a]	160.1 (1.7%)	1614 (−5.2%)	13675 (−9.5%)	86.4 (−7.6%)[b]	705.8 (−6.6%)	882.7 (−9.9%)	0.342
Average US grid[c]	416.8	3329.9	3207.5	44.1	2136.0	989.1	0.257
Willow production & transport with…[d]							
NREL gasifier	69.9 (−83.2%)	645.0 (−80.6%)	373.9 (−88.3%)	524.6 (1089%)	34.0 (−98.4%)	38.9 (−96.1%)	13.3
EPRI gasifier	277.3 (−33.5%)	816.6 (−75.5%)	941.9 (−70.6%)	105.5 (139.1%)	>31.4 (−98.5%)[e]	40.2 (−96.0%)	12.9
EPRI direct-fired	1769.2 (324.4%)	278.9 (−91.6%)	>161.0 (−95.0%)[e]	235.9 (434.6%)	>40.8 (−98.1%)[e]	52.3 (−94.7%)	9.9

- 10% co-firing reduced Hg emissions by 8.4% (Heller et al. 2004)

Geographic Potential



Fuel transport schematic. (source: Cornell University *Sustainable Campus*)



Surface mines, coal energy and biomass energy facilities in West Virginia (source: US Energy Information Administration).

Shrub Willow

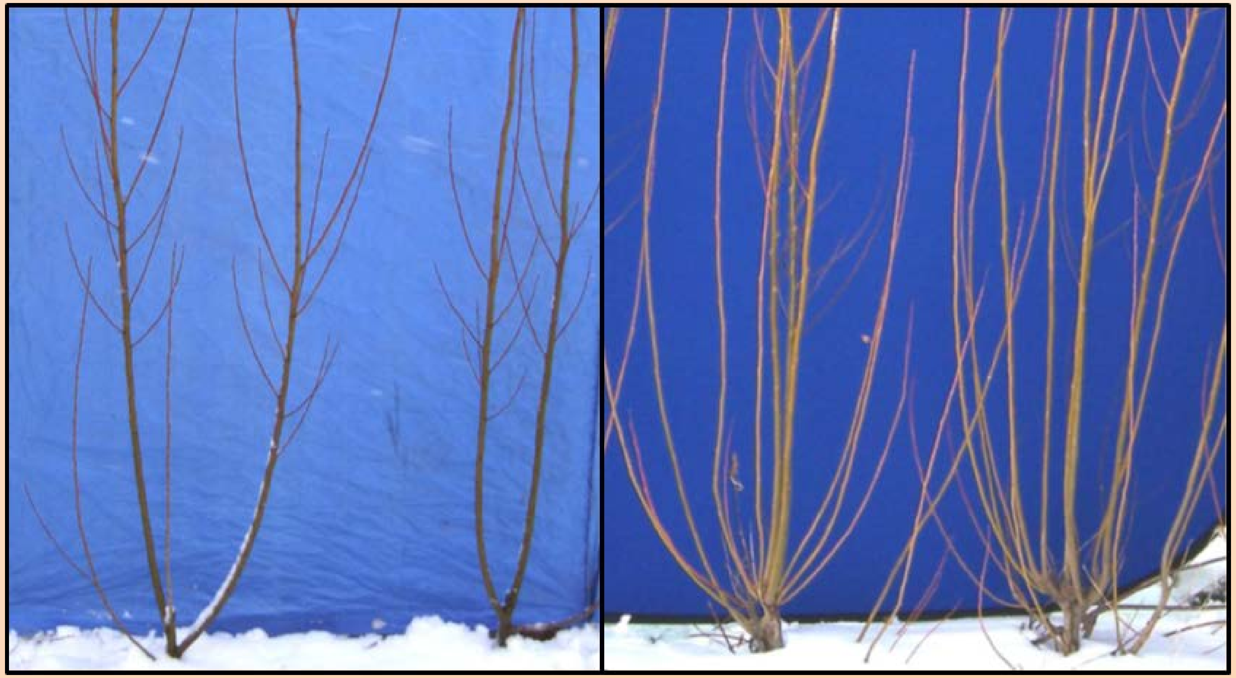
- *Salicaceae, Salix spp*.
- Woody shrub
- Robust branch structure
- Over 125 varieties
  - growth habit
  - climate adaptation
  - site tolerance
  - genetic improvements

Willow shrub.

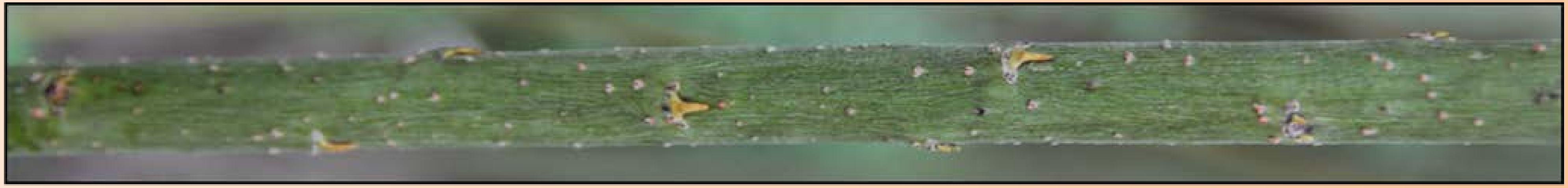
Clockwise from top left:
Red Curly, S365, Allegany, Fish Creek (source: Double A Willow, Inc. Fredonia, NY)

Why Willow?

- Vigorous clonal rooting
- Site adaptability
- Fast growth
- Responds to coppicing
- Perennial, 20 + year rotation
- High yielding – up to 11 odt ha^{-1} (oven dry tons per ha)



Willow before (left) and after (right) coppicing.
(source: Heavy and Volk, 2013)



Preble willow cutting. (source: Cornell University *Willowpedia* fact sheet)

Plantation Culture

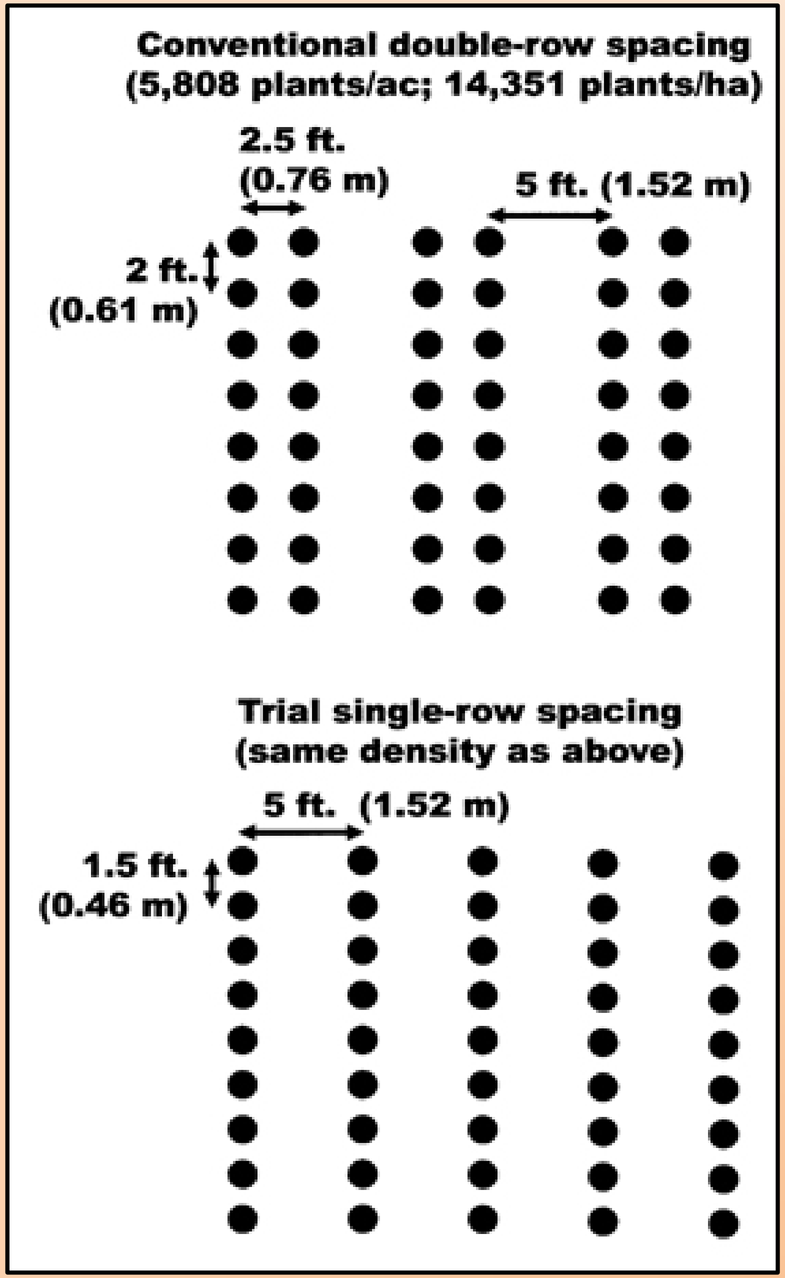
- Vegetative propagation
  - Planting of dormant cuttings or whips
    - 20 cm to 50 cmstakes
    - 1 to 2 m whips

Willow whips
source: salix-willows.blogspot.com

Rooted willow cutting

Plantation Culture

- Row Cropping
  - 14,000 stems ha^{-1} (McCracken et al. 2010)
  - Control competing vegetation
  - Fertilize: 100 kg N ha^{-1} (Abrahamson et al. 2010)



Willow cropping schemes. (source: Cornell *Willowpedia*)

Plantation Culture

Willow biomass crop operation schedule
(Keolian and Volk, 2005)

Year	Season	Activity
0	Fall	Mow, contact herbicide, plow, disk, seed covercrop, cultipack
1	Spring	Disk, cultipack, plant, pre-emergent herbicide, mechanical and/or herbicide weed control
1	Winter	1st year coppice
2	Spring	Fertilize
3		
4	Winter	1st harvest
5	Spring	Fertilize
6		
7	Winter	2nd harvest
(8–22)		(Repeat 3 year cycle for 3rd–7th harvest)
23	Spring/Summer	Elimination of willow stools

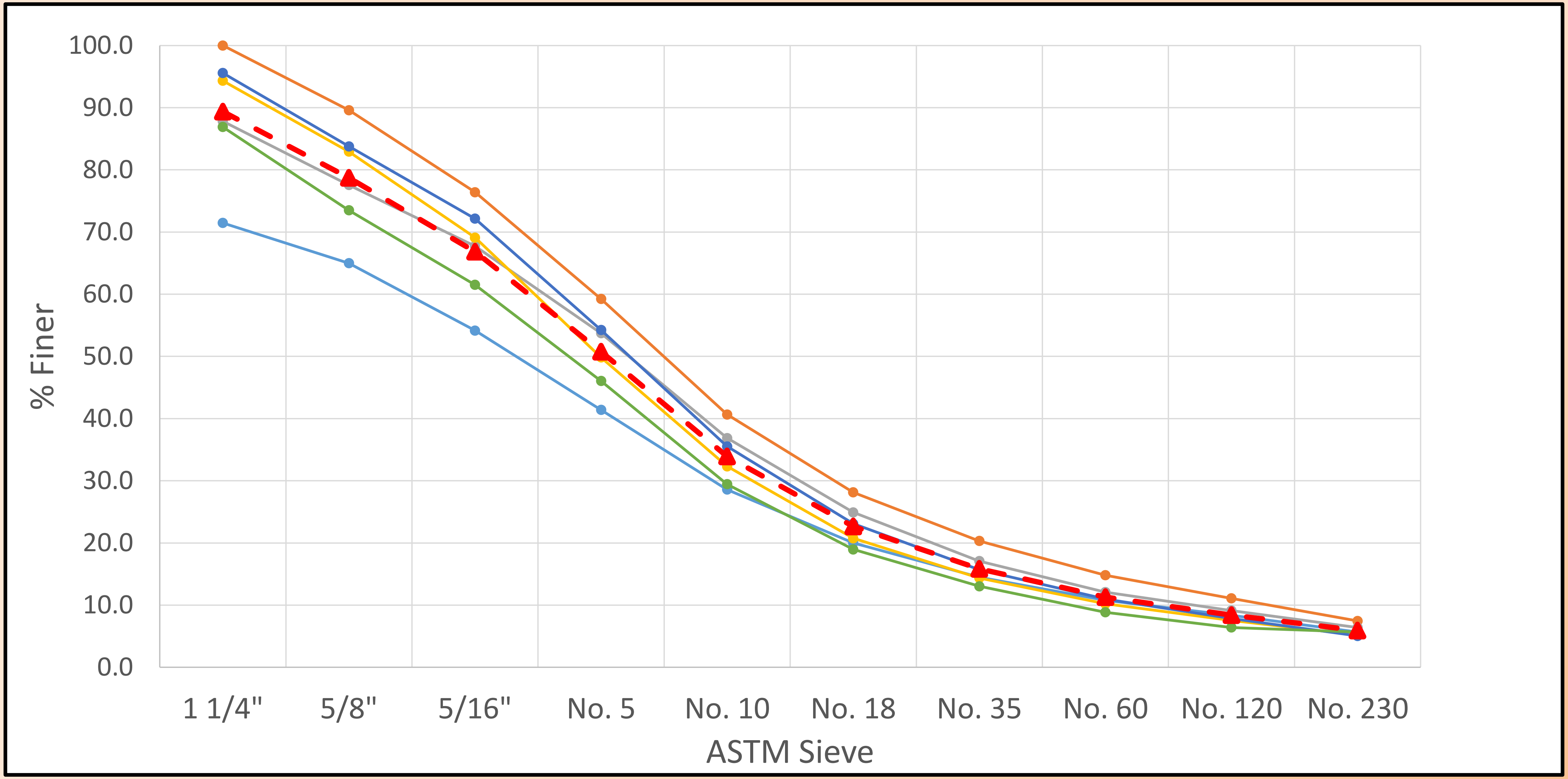
- Short Rotation Coppice (SRC) system
- 23 year rotation
- Seven 3 year harvest cycles
- Low annual energy inputs!

Suitable Soils

Suitable and unsuitable soil characteristics for shrub willow crops (Abrahamson et al. 2002)

Soil Characteristic	Suitable	Unsuitable
Texture	Loams, sandy loams, clay loams, silt loams and clay	Sandy, course sand & gravel, heavy clay with standing water
Structure	Well developed to single grain structure	Massive or lacking structure
Drainage	Imperfectly to moderately well drained	Excessively well or very poorly drained (standing water)
pH	5.5 to 8.5	Below 5.5, above 8.5
Depth	18 inches or more	Less then 18 inches

Minesoil Texture



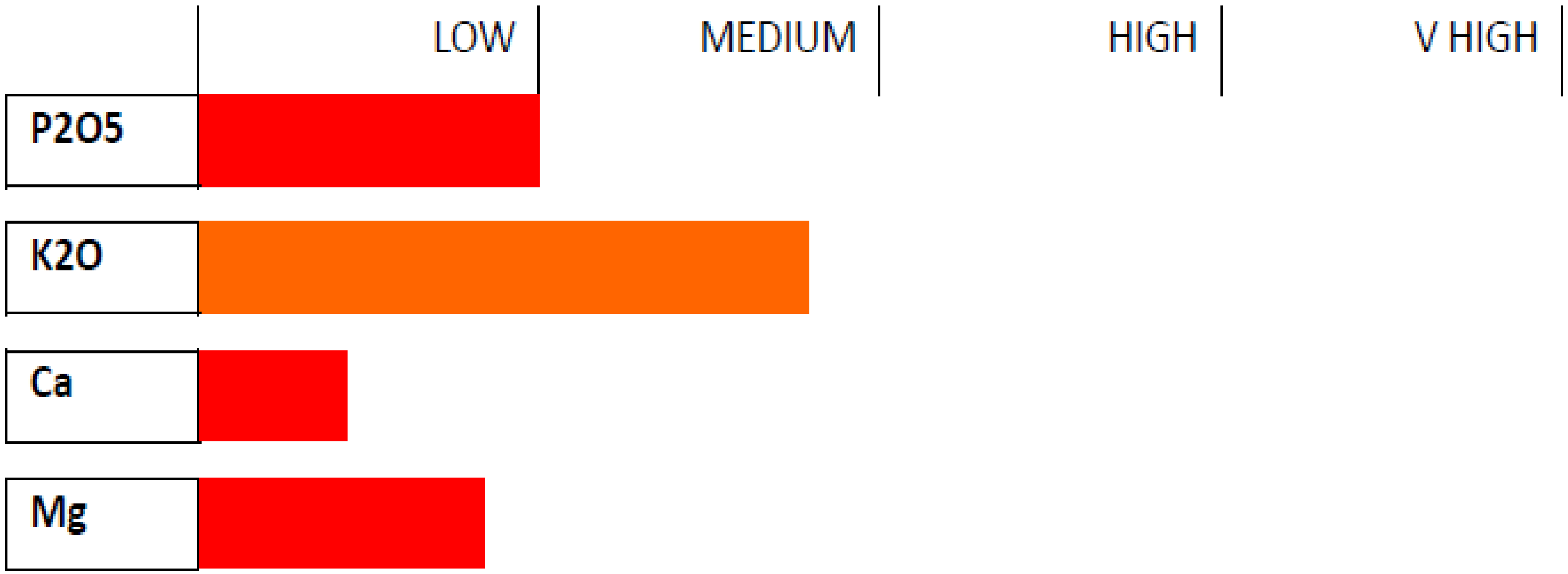
Minesoil Ammendments

Reclamation soil amendments and seed mix at the C-1 mine.	
Soil Amendments	
Lime Amendment	5 Mg ha^{-1}
Fertilizer	1,100 Mg ha^{-1} 10-20-20
Mulch	2,200 Mg ha^{-1}
Seed Mix	
Birdsfoot Trefoil	17 kg ha^{-1}
Orchard Grass	17 kg ha^{-1}
Red Top	6 kg ha^{-1}
Oats/Perennial Rye/Japanese Millet	50 kg ha^{-1}

Minesoil Fertility

LAB TEST RESULTS

Nutrients	Values	Rating
Soil pH	4.6	L.R.: 6.3
P2O5(Lbs/A)	25	LOW
K2O(Lbs/A)	95	MEDIUM
Ca(Lbs/A)	441	LOW
Mg(Lbs/A)	83	LOW



Nutrients	K	Ca	Mg	H	Total[CEC], BS(K+Ca+Mg)
MEQ/100	0	1	0	13	14
%Sat	1	8	3	89	13

Minesoil Variability

Biomass Yields

- Commercial Target
  - 7.5 odt ha^{-1} yr^{-1} (Larsson et al. 1998)
- Agricultural Soils
  - 8 to 11 odt ha^{-1} yr^{-1} (Volk et al. 2006)
- Mine Soils
  - Difficult to standardize

Harvest on agricultural soils. (source: Cornell University *Willowpedia*)

One year growth on mine soils.

Study Focus

- Silvicultural treatments to overcome poor edaphic conditions.
- Quantified first year growth differences
  - Three clones
  - Fertilizer amendments
  - Two planting methods

Planting Stock

- SX61 (*Salix sachalinensis*)
  - Rust and beetle resistant
  - Female only, viable seed
  - Yield: 9-13.5 odt ha^{-1}
- Fish Creek (*Salix purpurea*)
  - Cross of ‘94006’ and ‘94001’
  - Rust, beetle, sawfly resistant
  - Male only
- Preble (*Salix viminalis x Salix miyabeana*)
  - Rust, beetle, sawfly resistant
  - Sterile triploid
  - Yield: 4.5-13.5 odt ha^{-1}

Fish Creek (source: Cameron et al. 2007)

SX61 (source: Cameron et al. 2007)

Preble (source: Gouker et al. 2015)

Methods

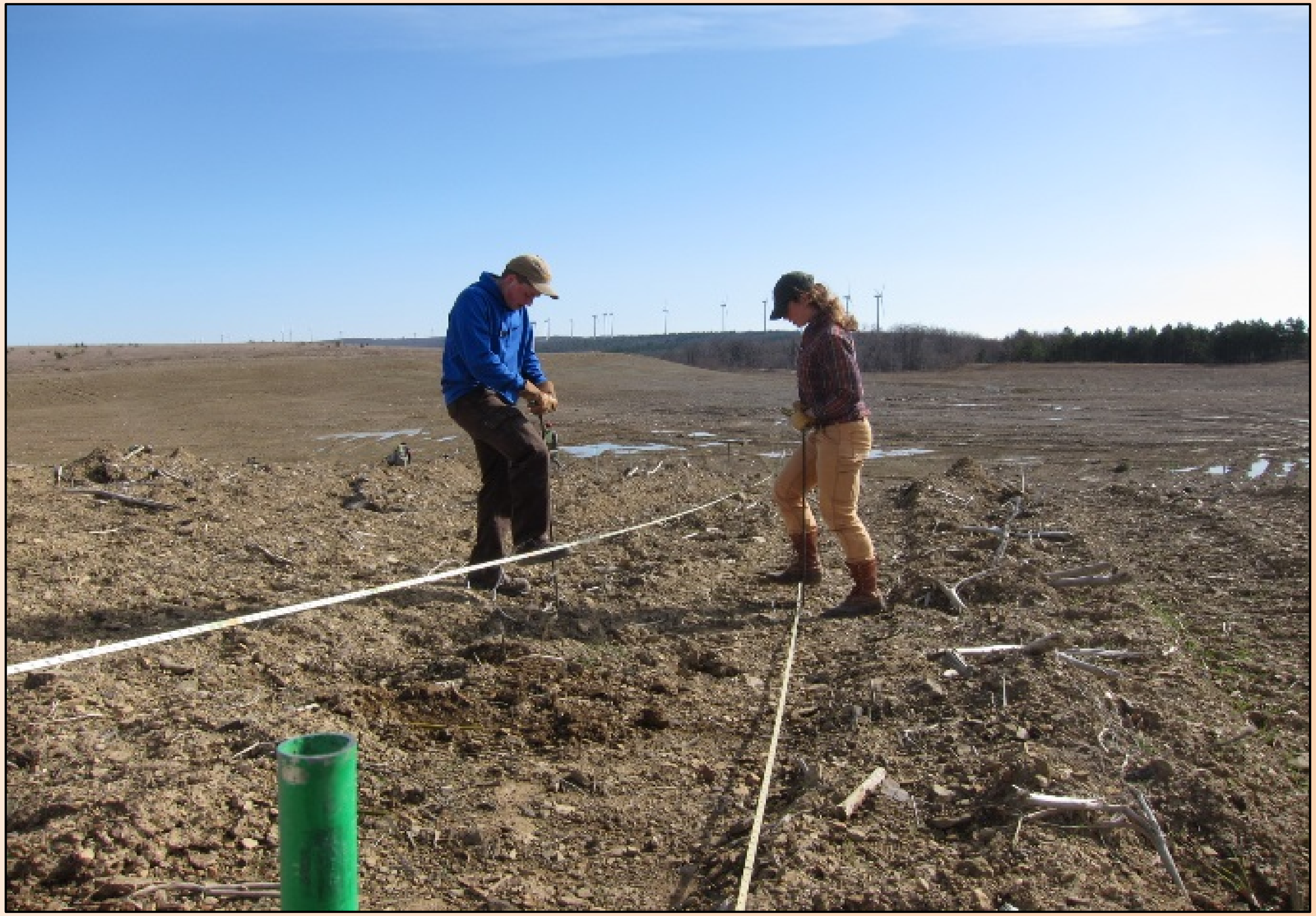
- Planted April 2015
- Treatments
  - Planting orientation
  - Fertilizer Treatments at 125 kg N ha^{-1}
    - No fertilizer
    - Controlled release
    - Traditional fertilizer

Planting Method

Horizontal

Planting Methods

Vertical



Experiment Layout

Experimental layout showing one replicate.

Measurement & Analysis

- September 2015
- Basal diameters of each branch
- Total plant height
- Volume index (cm^3) per sub-plot = $\Sigma D^2 H$
- Three-factor ANOVA
  - Assessed significant differences among fertilizer, clone, and planting position factors.

Survival

Willow survival by planting method.

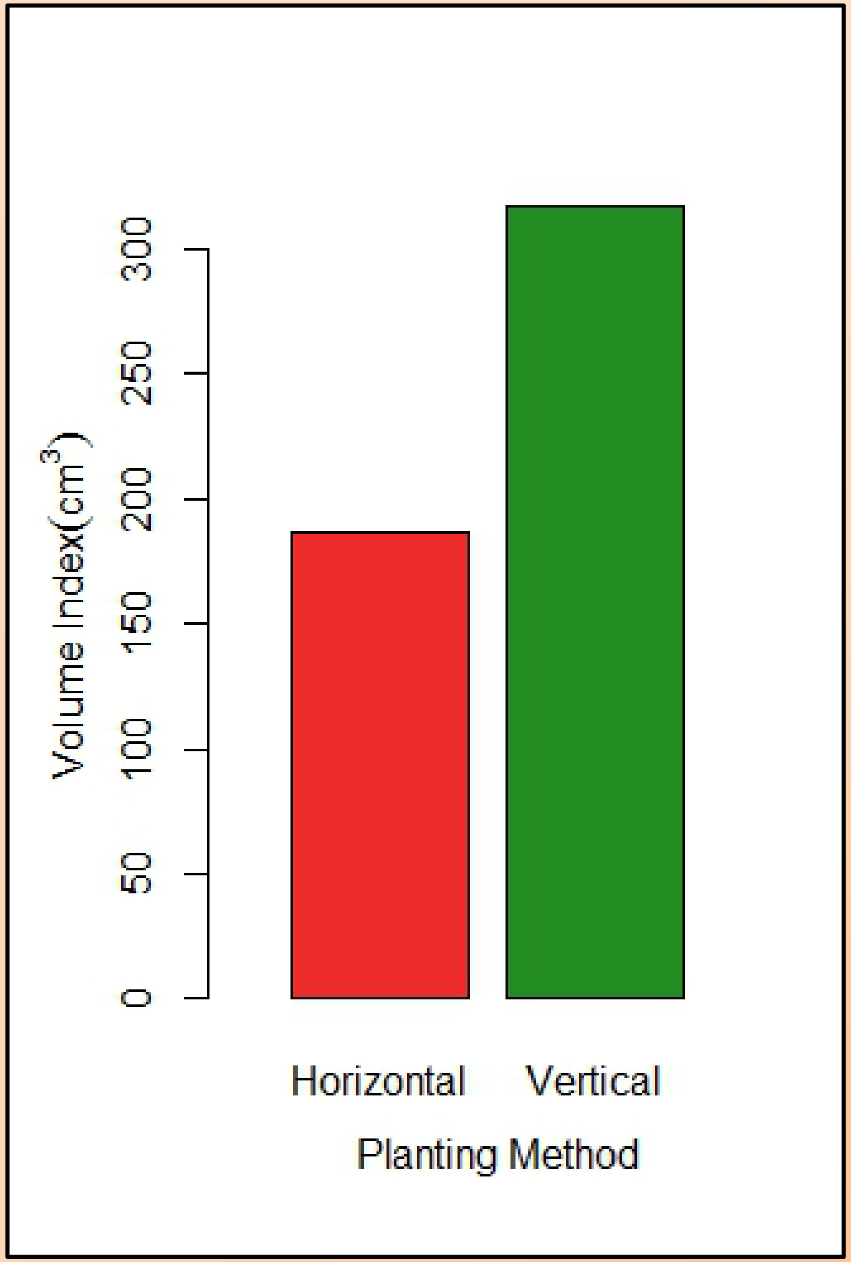
Planting Method	Survival count	Survival %
Horizontal	235	65
Vertical	334	93

Willow survival by clone.

Clone	Survival count	Survival %
FCR	176	73
PRB	214	89
SX61	179	75

Results

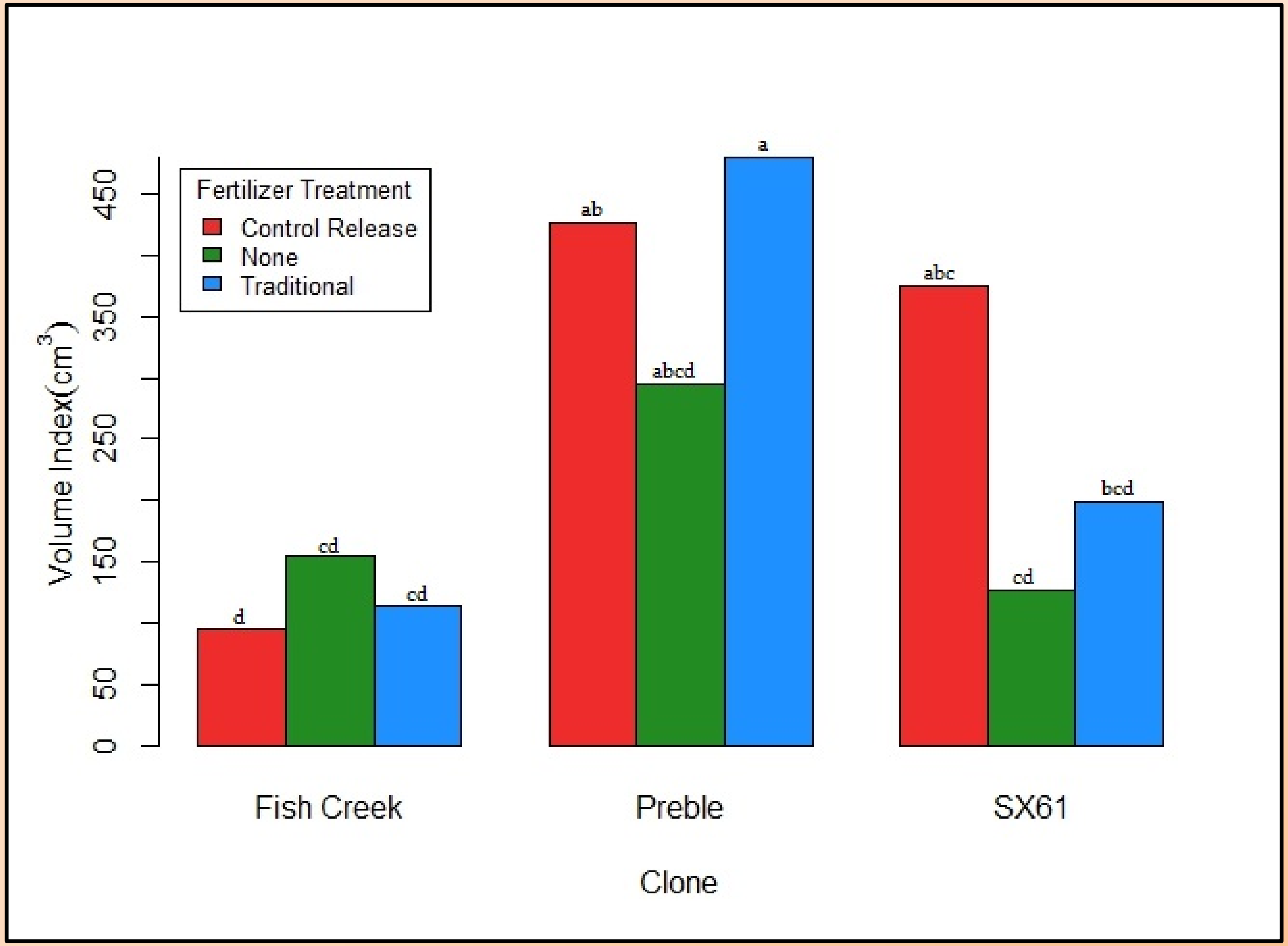
- Planting position affected the volume index ($p=0.0015$) across all treatment factors.
- Vertically planted cuttings had 70% greater mean volume indices compared to horizontally planted cuttings.



Response to planting method

Results

- Clone X fertilizer treatment (p=0.0495)
  - Inconsistent fertilizer response
  - Clonal growth differences
- Preble
  - Responded to fertilizer
  - Best growth overall
- SX61
  - 2nd in fertilizer response
- Fish Creek
  - Poorest performance



Response of Clone X Fertilizer treatments.

Discussion

- Relatively larger volumes of Preble cuttings were interpreted adaptability site conditions
  - We hypothesize…
  - Superior WUE
  - Superior NUE
- Fewer significant responses to fertilizers within clone groups, may be due to…
  - variability of reclaimed soils
  - limited response time

Conclusions

- Shrub willow did survive the first growing season on the mine soil.
- Horizontal planting not successful in overcoming rocky planting conditions
  - May need deeper, mechanically created furrow (i.e. Larsen et al. 2014)
- A clone's site tolerance was interpreted as the paramount factor influencing first year growth.

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