NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Waste-to-Energy Resource Assessment

Preliminary Report

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June 22, 2016

Waste-to-Energy Resources Overview

- Solid WtE resources (e.g. MSW wood, yard waste)
- **Wet (liquid) WtE resources:**
  - Wastewater sludge
  - Animal manure
  - Food waste
  - Fats, oils and greases (FOG)

Goal: Provide estimates of wet WtE feedstock availability at finer than national level geography – county or point location.

Food Waste

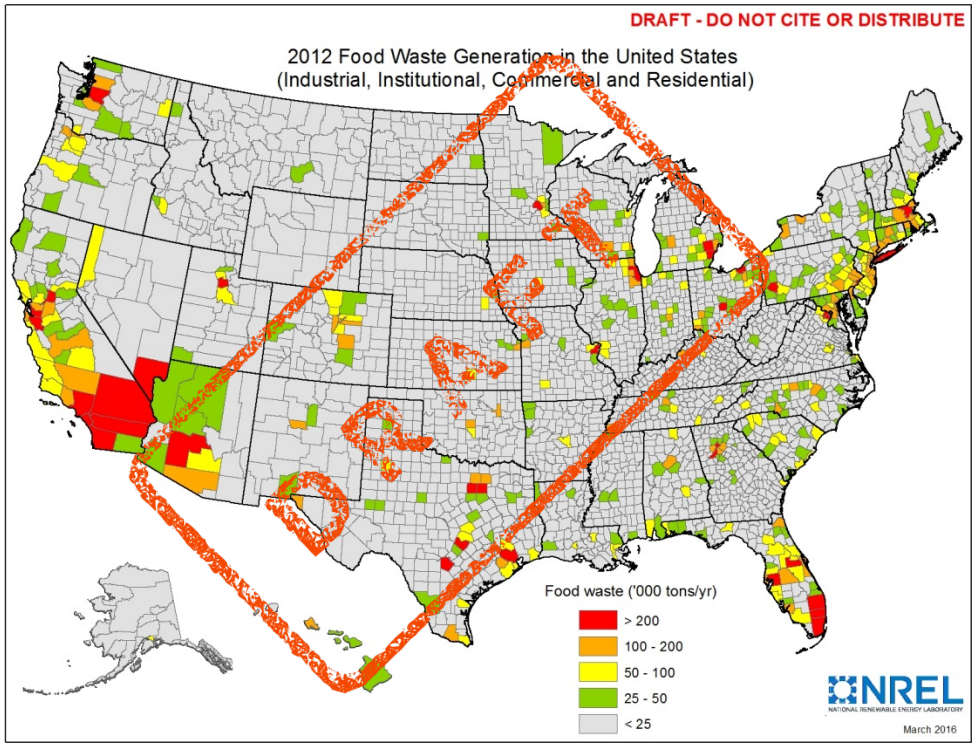
- **Industrial**

  Food and beverage manufacturing (NAICS codes 311/// and 3121//)

  Food and beverage wholesalers / distributors (NAICS codes 4244//, 4245//, and 4248//)
  - Fruit and vegetable canneries
  - Dehydrated and fresh/frozen fruit and vegetable processors
  - Dairy creameries (milk, cheese, yogurt, ice cream/butter)
  - Wineries
  - Meat packing and processors (poultry, fish and red meat)
  - Slaughterhouses
  - Coffee/tea production
  - Breweries and distilleries
  - Bakeries
  - Grain mills
  - Soft drink bottling plants
  - Other
- **Institutional**
  - Hotels/motels
  - Hospitals
  - Nursing homes
  - Colleges, universities, schools and day cares
  - Correctional facilities
- **Commercial**
  - Supermarkets
  - Restaurants
- **Residential (includes military bases)**

Draft Food Waste Generation Estimate

- IIC food waste estimates are based on:
  - Number of businesses and employees from the 2012 County Business Patterns (US Census Bureau)
  - Ratio of food disposed per employee or number of beds/students/inmates
  - Exclude some businesses with less than 5-10 employees (under revision)
- Residential food waste estimates are based on per capita food waste generation:
  - Per capita estimates vary from 0.03 tons/person/year to 0.23 tons/person/year.
  - Literature review identified a clustering around 0.13 tons/person/year
- NREL's analysis does not include food loss at primary level (farm to retail) which is under investigation:
  - For fresh fruits/vegetables the loss is small (on average, 3-10% of primary-to-retail weight)
  - For frozen fruits/vegetables the loss is higher, much higher than that at retail/consumer level (on average, 40-80% of primary-to-retail weight)



Draft Food Waste Generation Estimate (cont.)

Draft Food Waste Generation in 2012

Sector	tons/yr	%
Residential	39,551,703	66
Commercial	13,964,036	23
Institutional	5,931,148	10
Industrial	711,213	1
Total	60,158,100	100

Results Comparison

Study	**Food waste (million tons/yr)**
NREL (2012, food generation)	60
NREL (2012, conservative residential food waste)	39
EPA (2012, food disposal)	37
BSR (2012, food generation)	61
USDA (2010, food loss/generation)	66

Food Waste Disposal/Diversion in 2012

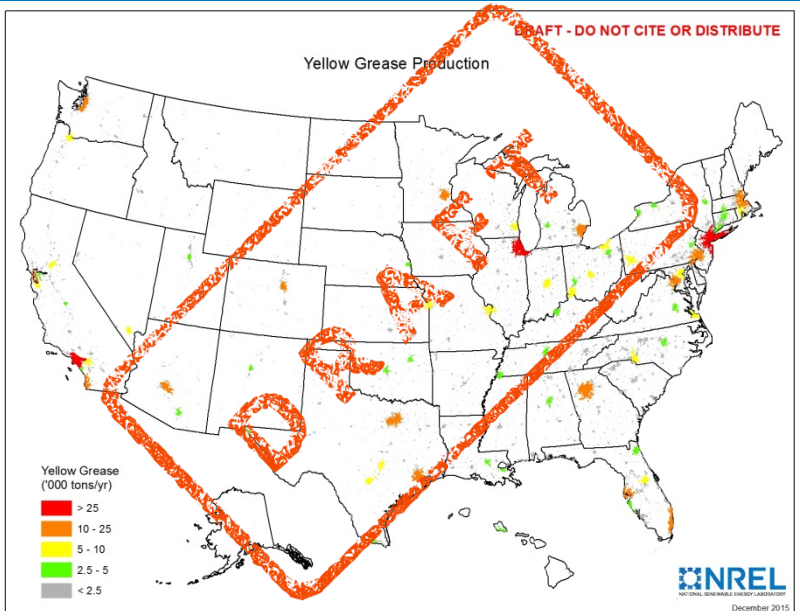
Method	%
Landfills	58
Composted with other green material	3 - 7
Food donation (food banks)	1.7
Animal feed (swine)	0.20 - 0.32
WtE (co-digestion, dry fermentation)	n/a

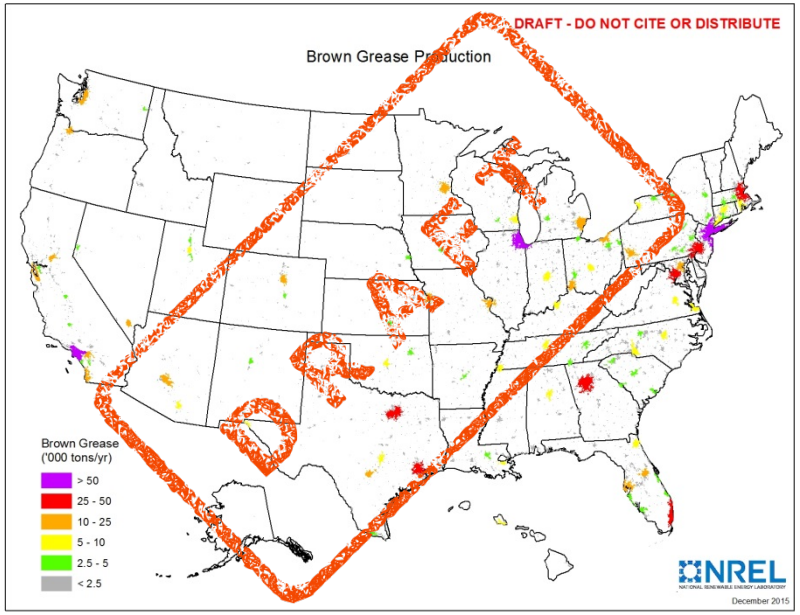
FOG Overview

- **This category includes the following resources:**
  - Yellow grease (refined used cooking oil)
  - Brown grease (trap/interceptor grease)
  - Animal fats (inedible tallow, choice white grease, and poultry fat)

Yellow and Brown Grease

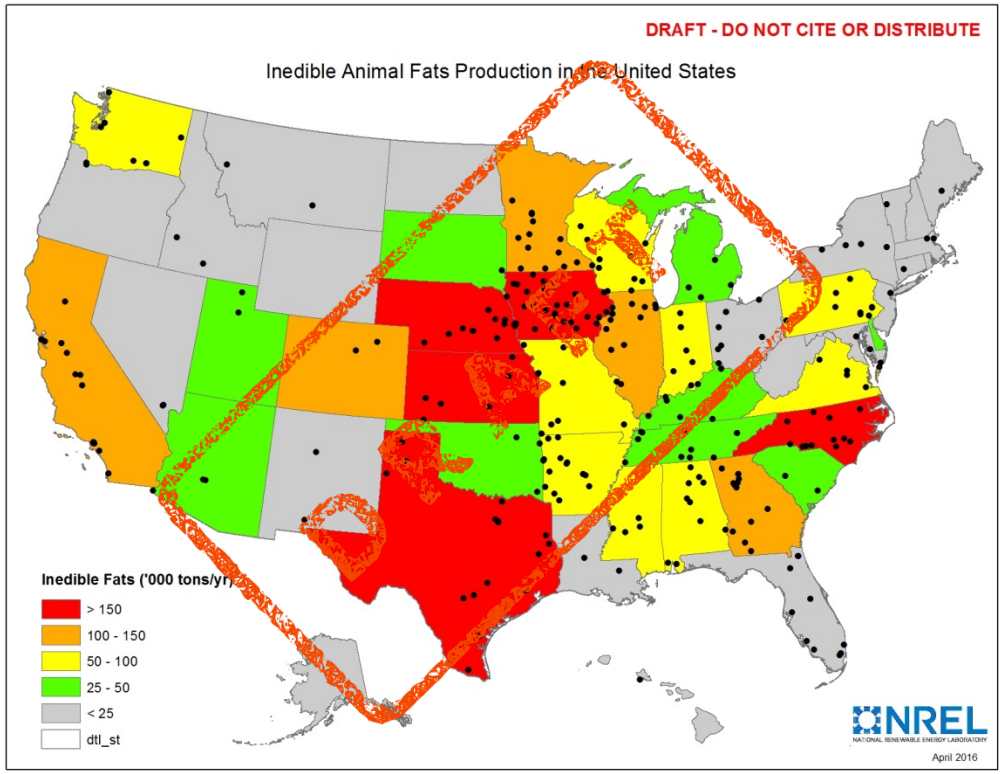
- Estimates are based on population numbers and yellow grease generation per capita
- Highly populated areas are sources of large grease generation.





Inedible Animal Fats

- Feedstock type:
  - Inedible tallow
  - Choice white grease
  - Poultry fat
- Top down approach based on:
  - Animal slaughter data by state from USDA (cattle/calf, hogs, chicken and turkey)
  - Percent fat of the live weight for each animal type
  - Subtract edible fats
- Disaggregation methodology to point location and county level is underway:
  - Rendering plants – independent and integrated (e.g. Smithfield, Tyson, Cargill)
  - Number of employees per business



Note: map includes all livestock rendering plants and select poultry-processing plants (e.g. Tyson, American Proteins, Keystone, etc.)

Preliminary FOG Estimates

Commodity	NREL (2012)	NRA (2012)	USDA (2015/2016)
Edible tallow	929,191	895,077	446,644
Inedible tallow	1,651,895	1,601,879	1,677,812
Choice white grease	691,799	584,556	676,294
Lard	85,503	70,217	180,920
Poultry fat	830,864	523,377	1,180,580
Yellow grease	1,104,192	976,538	979,973
Brown grease	1,666,258		
Other grease (brown grease?)			378,901
Total (minus brown grease)	**4,278,750**	**3,686,350**	**4,514,660**
Total (with brown grease)	**5,945,008**		**4,893,561**

Data in short tons

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Wastewater Sludge and Manure Resource Assessment -Approach and Results

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Publically-Owned Treatment Works (POTWs) Sludge Resource Assessment

- Duel approaches to estimate and validate estimates for raw sewage sludge solids on a site specific basis

  - **Top down (estimation):** use site specific gross influent flow and engineering factors (Metcalf & Eddy) to estimate the fraction of solids removed during primary and secondary treatment ***complete***

  - **Bottom up (validation):** use site specific pollutant monitoring and loading data to develop regression curves (flow vs sludge) and mean percent removal ***in-progress***

Publically-Owned Treatment Works - Sludge

Annual influent flow approach with fixed values for {*f*, *ss*, *k*, *BOD*}; variable *Q*

$W_s = W_{sp} + W_{ss}$

W_s = Total dry solids (g/d)

W_{sp} = Raw primary solids (g/d)

W_{ss} = Raw secondary solids (g/d)

Where,

$W_{sp} = f * ss * Q$

f = fraction of suspended solids removed in primary settling

ss = suspended solids concentration in (g/m^3)

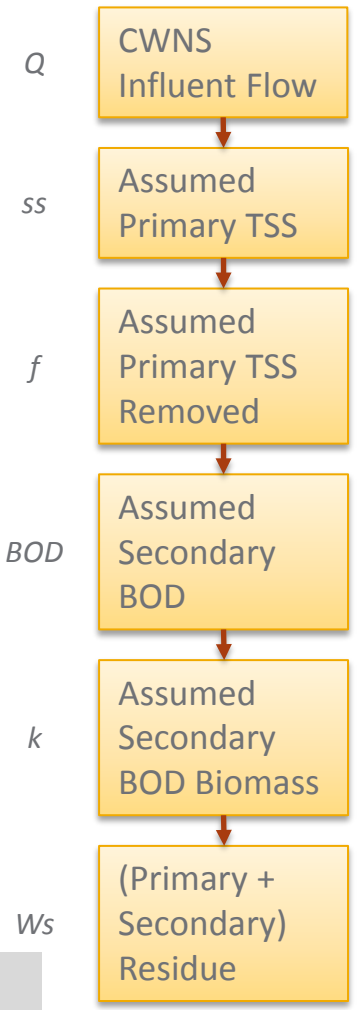
Q = flow rate (m^3/d)

And,

$W_{ss} = k * BOD * Q$

k = fraction of BOD that becomes excess biomass

BOD = biological oxygen demand (g/m^3)



- Q = CWNS 2012 influent flow (mgd); 10,922 facilities
- Assumed: f = 0.5; k = 0.35 ss = 0.4; BOD = 0.25

Preliminary Sludge Estimates

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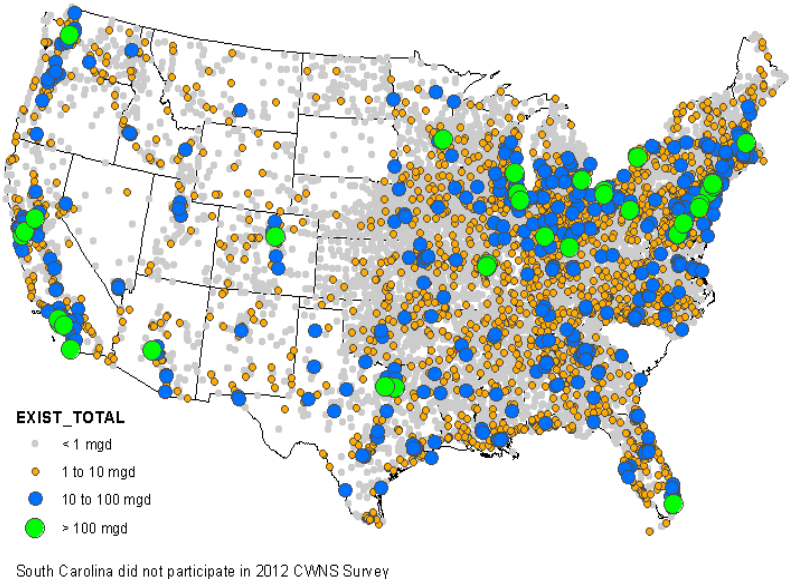
Raw Sewage Sludge (DT/y)

	Min	Max	Mean	Sum
Total	22	350000	1250	**13,700,000**
Primary Sludge	11	186,000	665	7,265,000
Secondary Sludge	10	164,000	588	6,427,000

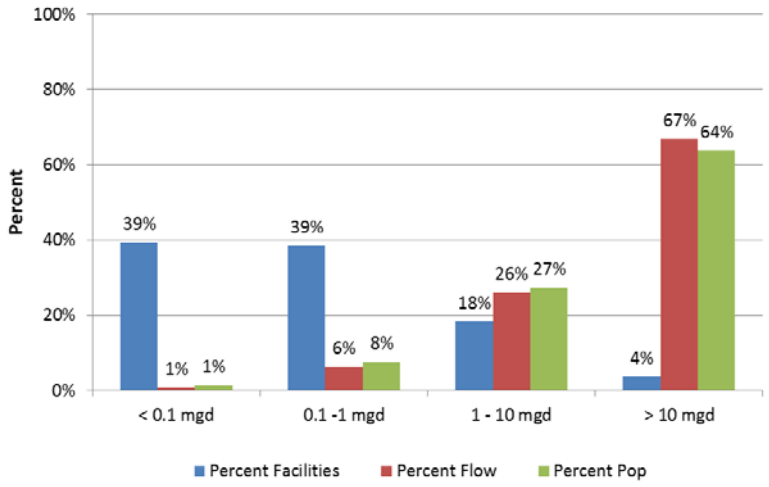
Previous Estimates

2008	7.18 DT/y	Treated Biosolids	Beecher et al., (2007). A National Biosolids Regulation, Quality, End Use, and Disposal Survey, which reports 7.18 dry US tons of treated biosolids in the 2004.
2008	5-7.1 DT/y	Treated Biosolids	Materials Characterization Paper (provided by Bruce Ritman). [References WEF 2002 and NBP 2005, p. 19-1, which both reference back to EPA 1999.

Note: Biosolids are sludge treated (typically anaerobic digestion) for beneficial use –
primarily land application.



South Carolina did not participate in 2012 CWNS Survey



Manure Resource Assessment

Approach based on Kellogg et al. (2000) that blends current inventory data with updated manure coefficients and published confinement thresholds and factors.

1. 2016 livestock inventory for target animal types (state-level USDA surveys)
    1. Fattened Cattle
    2. Dairy Cows
    3. Market Swine
2. Obtain inventory by operation size from 2012 census of agriculture
3. Develop new “total confinement factors” by applying confinement thresholds and factors to 2012 census data
4. Adjust 2016 inventory for confinement using total confinement factors
5. Compute total, recoverable, and excess manure
6. Convert each to dry matter basis
7. Assign estimates at site-specific CAFO locations (NDPES permits)

Manure Resource Assessment - Animal Inventory

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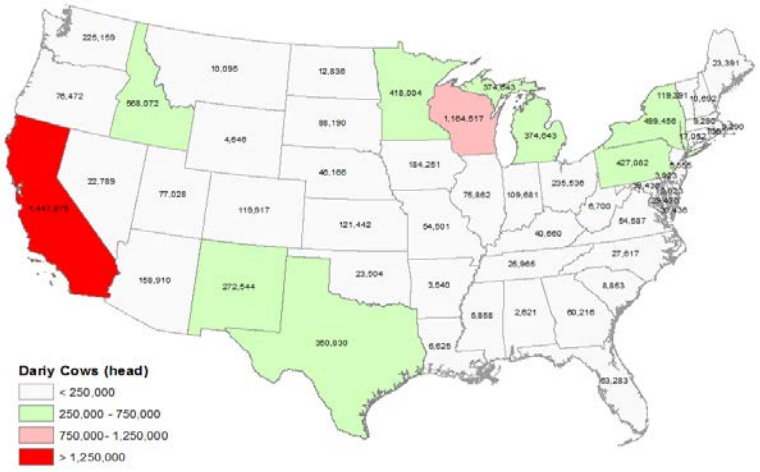
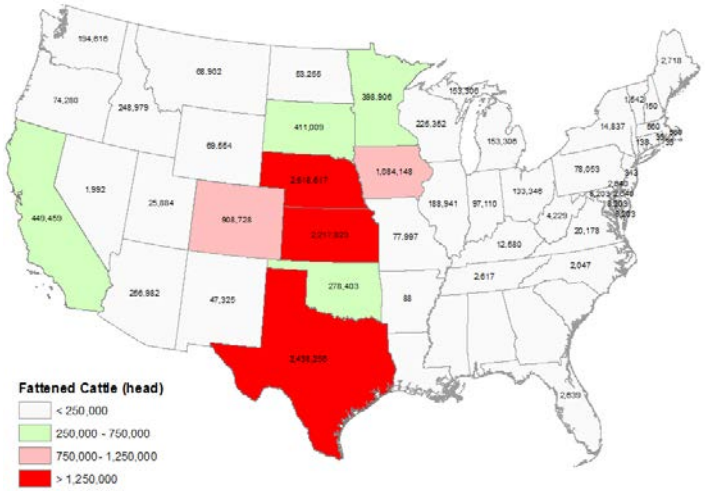
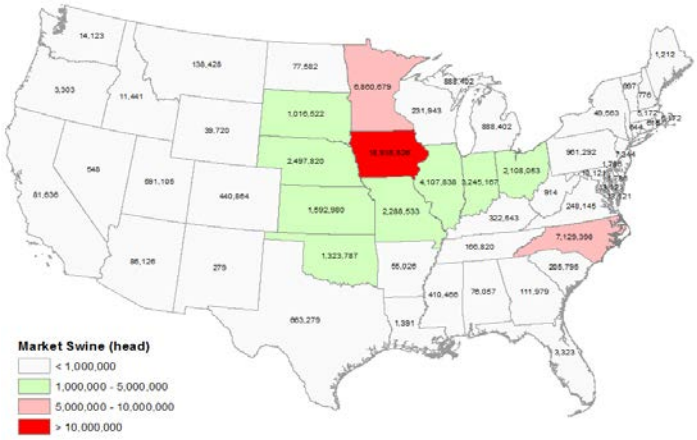
Dairy Cows



Fattened Cattle



Market Swine



Manure Resource Assessment - Inventory Comparison

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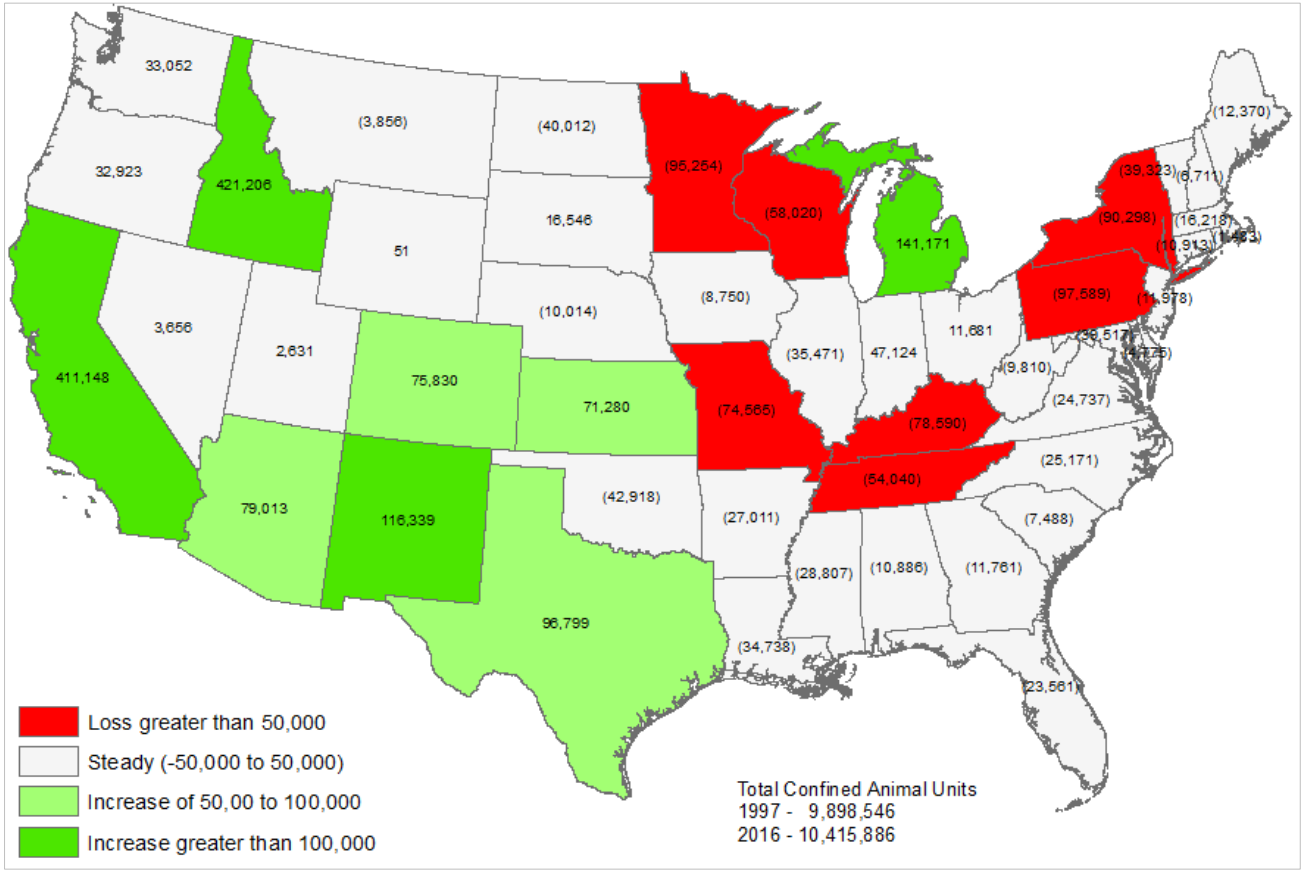
Comparison of confined dairy cows from 1997 to 2016



Manure Resource Assessment -Preliminary National Estimate (dry ton/y)

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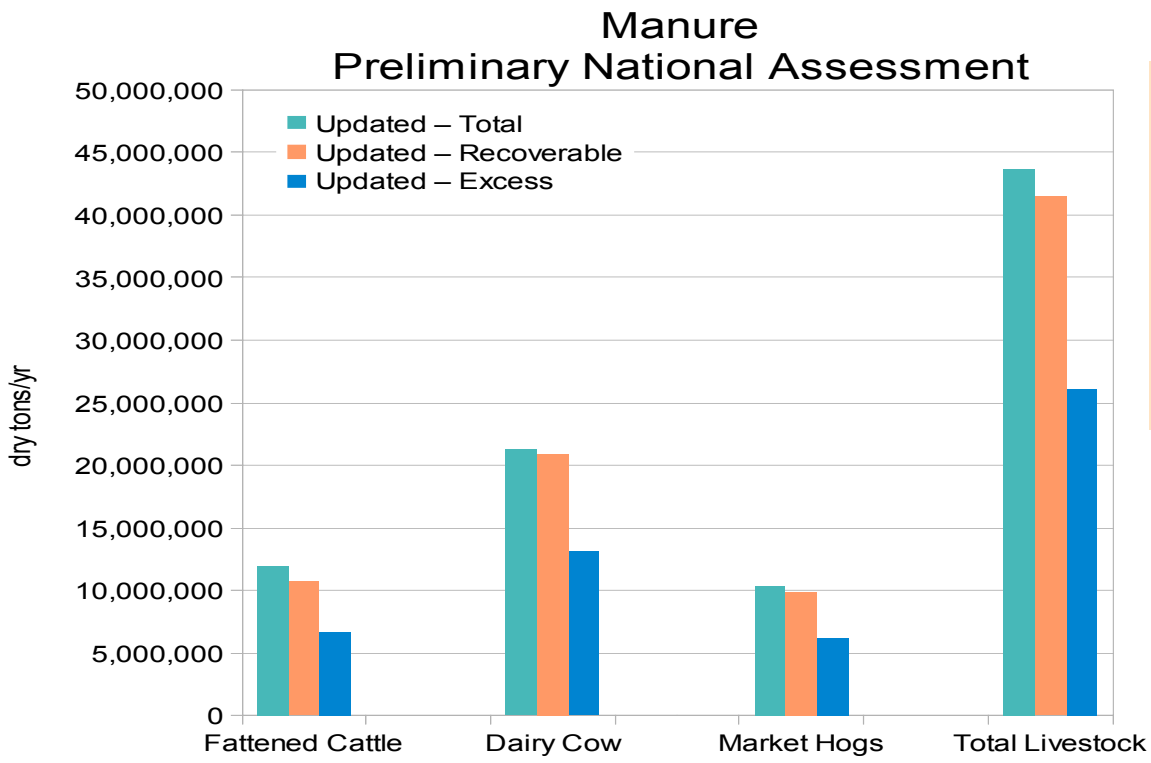

Fattened Cattle, also known as cattle on feed: steers and heifers fed for slaughter market.

Dairy Cows, also known as milk cows: female cattle that have calved and are bred specifically for high milk production.

Market Hogs: non-breeding hogs intended for slaughter.

Notes:

- Kellogg et al. (2000) estimated 452 M wet tons for all confined livestock.
- Kellogg et al., adjusted for dry weight and excluding poultry, breeding swine and other cattle: ~37 MDT
- Also differences in inventory and increase in individual animal manure production factors found in current literature.

Additional Slides

Evaluate the Biofuels Potential from Waste Assuming HTL Conversion

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Site-Specific Enterprise Scale: