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Article

Using Scenario Visioning and Participatory System Dynamics Modeling to Investigate the Future: Lessons from Minnesota 2050

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Appendix A. Baseline Model Parameters

The variables and conversion factors in the table below provided the baseline average for model parameterization. These factors were altered if explicitly or implicitly called for in the scenario. For example, if a scenario described the population in Minnesota 2050 as either ‘high’ or ‘low’, the model would be run with a population size increased above or decreased below this baseline, respectively.

Appendix A. Baseline Model Parameters.

Variable/Factor	Value		Data Source
Population in Minnesota	5,205,291		Minnesota State Demographic Center
Average water consumption per person	69.3 gallons/person/day		American Water Works Association
Industrial water use	161 billion gallons		Minnesota Department of Natural Resources water records database
Average statewide precipitation	28.4 inches		Minnesota Climatology Working Group
Average statewide precipitation during drought year	10 inches		Minnesota Climatology Working Group
Electricity demand per person	12.7 mwh/person		Minnesota Pollution Control Agency
Vehicle miles driven/person/year	10,415		Minnesota Pollution Control Agency
Passenger vehicle fleet fuel efficiency	20 miles/gallon		Minnesota Pollution Control Agency
Truck miles driven/year (diesel)	3.22 billion		Minnesota Pollution Control Agency
Truck fleet fuel efficiency (diesel)	5.68 miles/gallon		Minnesota Pollution Control Agency
Urban land area/person	0.74 acres		University of Minnesota Remote Sensing and Geospatial Analysis Lab
Home heating demand/person/year	54.8 mmbtu		Minnesota Pollution Control Agency
Heating fuels/acre (wood)	186.43 mmbtu		USDA Forest Service Forest Inventory & Analysis
Calories/person/day	2,800 Kcal		Estimate, based on UN nutritional requirements
Food calories/acre	1.4 million		Estimate, based on informal discussion with MN farmers
Irrigation intensity/food acre	0.6 acre/ft		2003 Minnesota Agricultural Census
Amt. food acres irrigated	Range: 2.5%–10% ag. area		2003 Minnesota Agricultural Census
Transportation fuel mix	Gasoline: 314 mil. gals Ethanol: 2.3 mil. gals Diesel: 9.8 mil. gals		Minnesota Pollution Control Agency
Electricity fuel mix (mmbtu)	*Coal* *Oil* *Gas* *Nuclear* *Hydro* *Wind* *Wood*	362,191,270 2,313,063 30,202,841 133,974,411 2,927,726 15,380,460 6,092,460	Minnesota Pollution Control Agency
Home heating fuel mix (mmbtu)	*Coal* *Natural Gas* *Wood* *Diesel* *LPG*	1,122,899 226,502,969 14,617,957 20,748,301 22,194,359	Minnesota Pollution Control Agency
Mmbtu/mwh conversion, coal	0.0917		Minnesota Pollution Control Agency
Mmbtu/mwh conversion, nuclear	0.0938		Minnesota Pollution Control Agency

Appendix A. *Cont.*

Variable/Factor	Value	Data Source
Mmbtu/mwh conversion, oil	0.0410	Minnesota Pollution Control Agency
Mmbtu/mwh conversion, gas	0.0703	Minnesota Pollution Control Agency
Mmbtu/mwh conversion, hydropower	0.2725	Minnesota Pollution Control Agency
Mmbtu/mwh conversion, wind	0.1172	Minnesota Pollution Control Agency
Mmbtu/mwh conversion, wood	0.0234	Minnesota Pollution Control Agency
Acres/mwh, wind electricity	0.000043	National Renewable Energy Laboratory
Acres/mwh, wood electricity	0.008814	Mann, M.K. and P.L. Spath. 1997. *Life Cycle Assessment of a Biomass Gasification Combined-Cycle Power Station.* Colorado: National Renewable Energy Laboratory.
Gallons water/mwh, coal electricity	210	U.S. Department of Energy. 2006. *Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water*. Washington: USDOE
Gallons water/mwh, nuclear electricity	590	*Ibid.*
Gallons water/mwh, oil electricity	430	*Ibid.*
Gallons water/mwh, gas electricity	290	*Ibid.*
Gallons water/mwh, hydroelectricity	4,500	*Ibid.*
Gallons water/mwh, wind electricity	1	*Ibid.*
Gallons water/mwh, wood electricity	330	*Ibid.*
Mmbtu/gallon gasoline	0.124	U.S. Department of Energy
Mmbtu/gallon ethanol	0.075	Oak Ridge National Laboratory
Mmbtu/gallon diesel	0.139	U.S. Department of Energy
Mmbtu/gallon biodiesel	0.130 (100% vegetable diesel)	North Dakota State University
Acres/gallon corn ethanol	0.0017	Minnesota Department of Agriculture
Acres/gallon prairie grass ethanol	0.0111	Tilman, D., Hill, J., and C. Lehman. 2006. Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass. *Science* 314: 1598-1600.
Acres/gallon poplar ethanol	0.0631	Production specifications of Range Fuels (funded by DOE): www.rangefuels.com
Acres/gallon soy biodiesel	0.01522	Estimated from Minnesota Department of Agriculture
Water consumption per gallon gasoline refining (taking place in Minnesota)	1.0 gallon	U.S. Department of Energy. 2006. *Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water*. Washington: USDOE

Appendix A. *Cont.*

Variable/Factor	Value	Data Source
Water consumption per gallon ethanol processing (including irrigation)	19 gallons	Minnesota Department of Agriculture
Water consumption per gallon biodiesel processing (including irrigation)	21 gallons	Minnesota Department of Agriculture; 2003 Minnesota Agricultural Census
Water consumption per gallon diesel processing	1 gallon	U.S. Department of Energy. 2006. *Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water*. Washington: USDOE
Job creation/gallon ethanol prod.	0.000020642	Minnesota Department of Agriculture

Appendix B. Scenario Parameters

Modeled parameters for each scenario that are different from the baseline parameters above are listed in the tables below. Note that these values are assumed for the year 2050.

Appendix B. Scenario Parameters.

Variable/Factor	Value		Data Source/Scenario Logic
Regional Self-Reliance			
Population in Minnesota	6,786,000		Population somewhat larger than current
Average water consumption per person	45.2 gallons		Water conservation in effect
Industrial water use	92.52 billion gallons		Industrial activity reduced compared with present
Electricity demand/person	10.7 mwh/person		Reduced to approx. 1990 MN levels
Vehicle miles/person/year	8273		Reduced to approx. 1990 MN levels
Passenger vehicle fleet fuel efficiency	22.7 miles/gallon		Fleet efficiency increased, but not by much—given no way to replace old cars
Truck miles driven/year (diesel)	0		Long distance trucking is no longer operating. However, some biodiesel is still used on-farm (approx. 75 million gallons)
Food calories/acre	817,600–1.4 million		Possibly more land-intensive farming methods (e.g., grass fed beef)
Transportation fuel mix	Ethanol: 4.3 billion gallons (92% from prairie grass; 8% from wood waste)		Fleet dependent on locally produced fuels; maximum wood from waste estimated using Minnesota BIOPET project numbers
Electricity fuel mix (mmbtu)	Coal	0	Dependence on local fuels
	Oil	0	
	Gas	0	
	Nuclear	0	
	Hydro	2,927,726	
	Wind	248,858,600	
	Wood	1,676,868,060	

Appendix B. *Cont.*

Variable/Factor	Value		Data Source/Scenario Logic
Regional Self-Reliance			
Home heating fuel mix (mmbtu)	*Coal* *Natural Gas* *Wood* *Diesel* *LPG*	0 0 1,208,053,186 0 0	Dependence on local fuels
Corporate Industrialism			
Population in Minnesota	6,786,000		Population somewhat larger than current
Average water consumption per person	69.3 gallons/person/day for wealthy people (5% of population); 45.2 gallons/person/day for other 95% of population		Divergence in living standards between wealthy, poor
Industrial water use	330.68 billion gallons		Industrial sector has expanded
Electricity demand/person	23.7 mwh/person for wealthy people (5% of population); 5.4 mwh/person for other 95% of population		Divergence in living standards between wealthy, poor
Vehicle miles/person/year	14,286 for wealthy people (5% of population); 5,757 for other 95% of population		Divergence in living standards between wealthy, poor
Passenger vehicle fleet fuel efficiency	Wealthy drive 35-mpg cars; poor rely on motor bikes (50 mpg) and buses (7 mpg)		Transportation mode similar to e.g., modern China
Bus and truck miles driven/year (diesel)	17.9 billion (bus); 5.4 billion (truck)		Buses being used for passenger transportation; trucks used for increased industrial transport
Home heating demand/person/year	54.8 mmbtu for wealthiest 5%; 26.17 mmbtu for bottom 95%		Divergence in living standards between wealthy, poor
Calories/person/day	3,500 Kcal for top 5%; 2,200 Kcal for bottom 95%		Divergence in living standards between wealthy, poor
Food calories/acre	1.08 million for top 5%; 1.6 million for bottom 95%		Wealthy eat more land-intensive diet (e.g., meat)
Transportation fuel mix (gallons)	Gasoline Diesel Biodiesel Ethanol	393,235,758 847,850,691 464,682,064 135,537,881	20% ethanol mixing in motor fuels; 20% biodiesel mixing
Electricity fuel mix (mwh filled by each fuel)	*Coal* *Oil* *Gas* *Nuclear* *Hydro* *Wind* *Wood*	27,209,449 66,567 1,339,670 12,190,166 797,776 0 0	Electricity mix approximately the same as at present, but renewable fuels have been eliminated (coal substitutes for these)

Appendix B. *Cont.*

Variable/Factor	Value		Data Source/Scenario Logic
Corporate Industrialism			
Home heating fuel mix (mmbtu)	*Coal* 0 *Natural Gas* *Wood* *Diesel* *LPG*	0 169,874,039 0 0 0	Assumed in scenario
Green Industrial Minnesota			
Population in Minnesota	8,212,229		High population growth due to green energy industry
Average water consumption per person	45.2 gallons		Water use in households is more efficient
Industrial water use	88.9 billion gallons		Industrial output has increased, but water use is more efficient
Electricity demand/person	26.2 mwh/person (in-state; electricity is also produced for export)		Some personal transportation is electric (see details below)
Vehicle miles/person/year	10,459		Increased personal travel compared with present
Urban land area/person	1.25 acres		Increased urban growth into rural areas of state
Passenger vehicle fleet fuel efficiency	Bullet train (electric): 0.03 kwh/person-km Personal Rapid Transit: 0.00013 mwh/person-mile Hydrogen fuel-cell vehicle: 0.000538124 mwh/person-mile to produce, compress hydrogen		Takagi, Japanese Railway & Transport Review *40*, March 2005; Dunning (ed.) 2003: Personal Automated Transportation (Advanced Transit Association); Qadrdan, M. & Shayegan, J. 2008. Economic assessment of hydrogen fueling station, a case study for Iran. *Renewable Energy* 33: 2525-2531.
Truck miles driven/year (diesel)	5.4 billion		Increased transportation needs due to industrial growth
Truck fuel mix	Algal biodiesel: 1.6 billion gallons		Parameters of scenario
Gallons biodiesel produced (including for export)	63 billion		Assuming all potential land is in biodiesel production (minus land required for electricity production)
Gallons water/gallon algal biodiesel	2.14 (assuming 90% water recycling)		Roger Ruan lab, University of Minnesota
Gallons algal biodiesel production/acre	5,000 (annually)		Roger Ruan lab, University of Minnesota
Home heating demand/person/year	Home heating is assumed to be entirely from geothermal sources and heat waste from industrial processes.		
Food calories/acre	No food is produced in Minnesota.		

Appendix B. *Cont.*

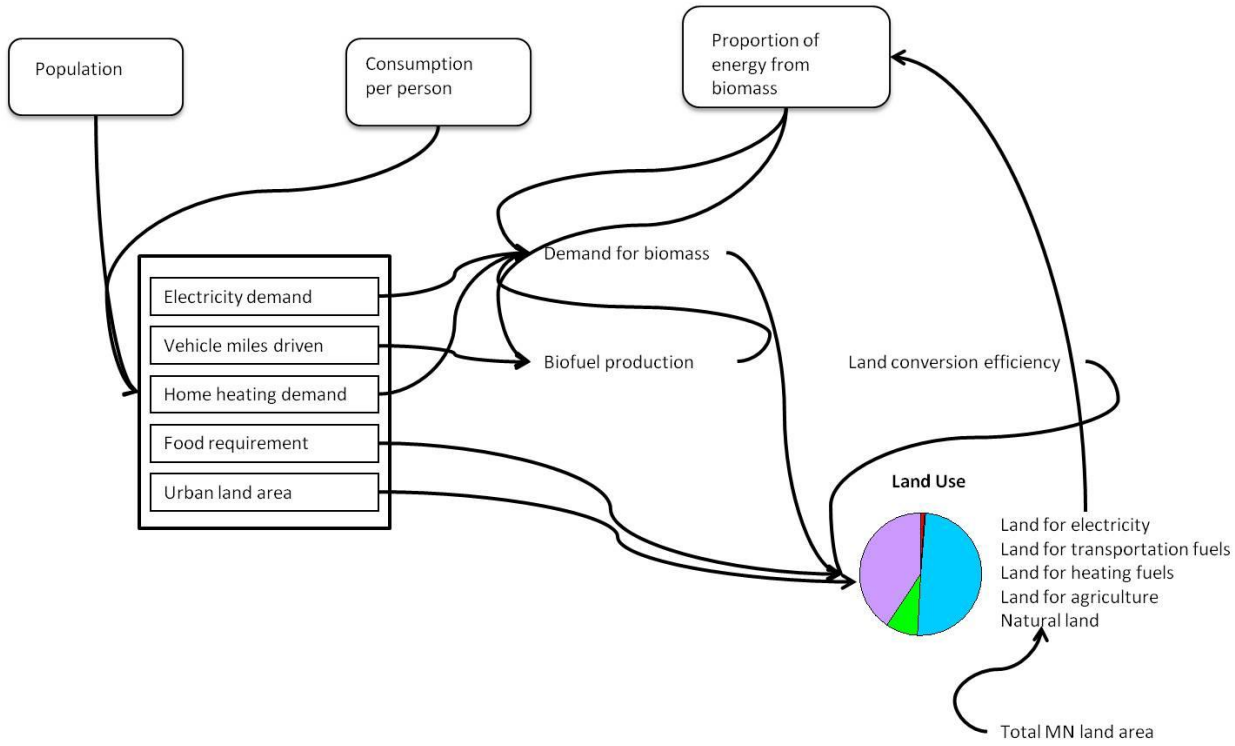
Variable/Factor	Value		Data Source/Scenario Logic
Green Industrial Minnesota			
Transportation fuel mix	50% of personal transportation takes place on electric trains; 25% on hydrogen fuel cell vehicles, and 25% on personal rapid transit.		Parameters described in scenario
Electricity fuel mix (mwh filled by each fuel)	Note: this scenario assumes Minnesota produces the maximum possible electrical output with this fuel mix, for in-state use and export		Maximum wind capacity calculated from National Wind. Solar roof potential for state calculated from Roofray: 11.4 watts/square foot average. 1/3 of urban land area in state assumed to produce solar roof electricity. Wave generation in Lake Superior calculated as: power in watt/meter = (water density (kg/m^3) × (acceleration due to gravity 9.8 m/s^2)^2 × period of wave (s) × wave height (m))/32 × pi [equation from U.S. Department of the Interior]. Data for calculations taken from NOAA buoy measurements in Lake Superior.
	Coal	0	
	Oil	0	
	Gas	0	
	Nuclear	0	
	Hydro	797,776	
	Wind	657,000,000	
	Wave Generation	2044	
	Solar Roofs	11,166,838,602	
	Wood	114,962,413	
Gallons water/mwh solar electricity	0		[assumed; no data available]
Gallons water/mwh wave generated electricity	0		[assumed; no data available]
Urbanized BioTechia			
Population in Minnesota	6,545,000		Population somewhat larger than current
Average water consumption per person	69.3 gallons/person/day for wealthy people (5% of population); 45.2 gallons/person/day for other 95% of population		Divergence in living standards between wealthy, poor
Industrial water use	330.7 billion gallons		Industrial sector has expanded
Electricity demand/person	23.7 mwh/person for wealthy people (5% of population); 5.4 mwh/person for other 95% of population		Divergence in living standards between wealthy, poor
Vehicle miles/person/year	14,286 for wealthy people (5% of population); 5,790 for other 95% of population		Divergence in living standards between wealthy, poor
Passenger vehicle fleet fuel efficiency	35 mpg for wealthy people (5% of population); 20 mpg for other 95% of population		The poor have older, less efficient cars than the wealthy
Bus and truck miles driven/year (diesel)	0		Long-haul trucking is non-existent; goods are consumed only within Midwest
Home heating demand/person/year	21.8 mmbtu for wealthiest 5%; 26.17 mmbtu for bottom 95%		The wealthy are using natural gas for home heating, which delivers more heat per energy unit than wood used by the bottom 95%.

Appendix B. *Cont.*

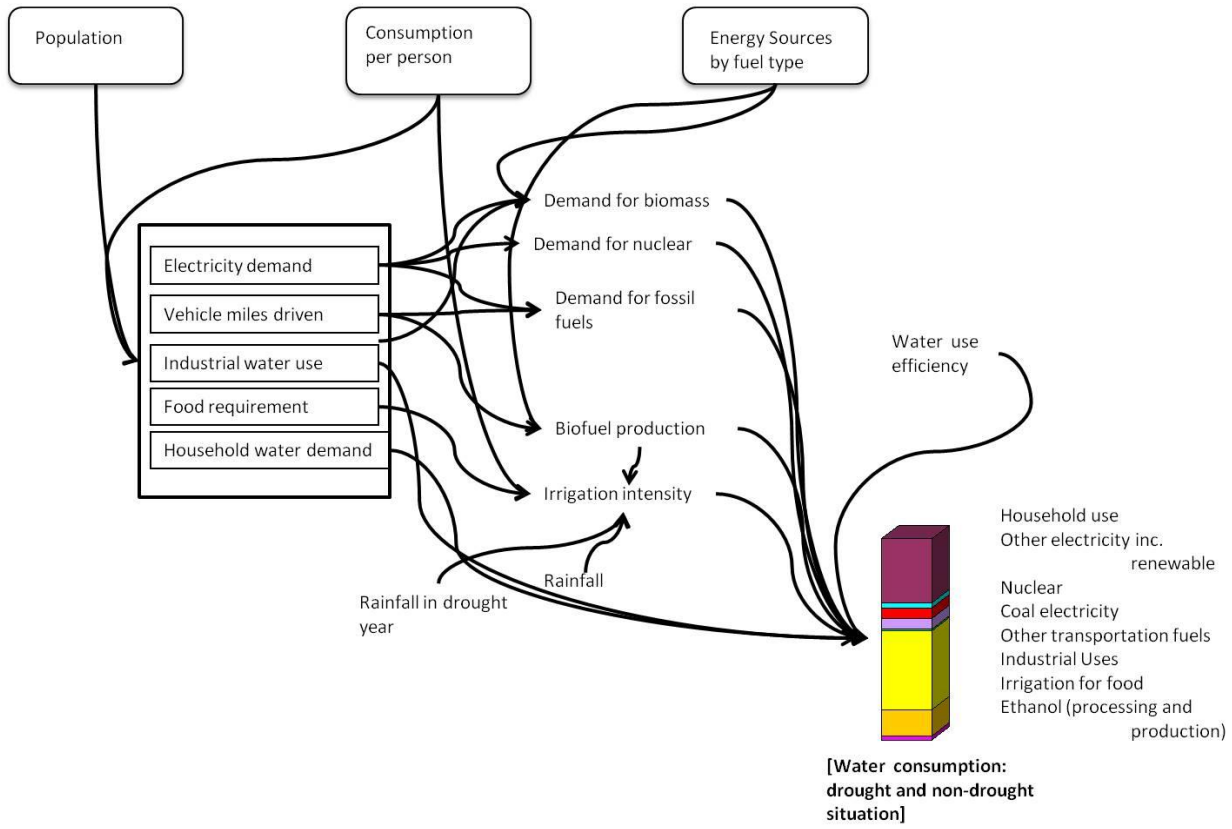
Variable/Factor	Value		Data Source/Scenario Logic
Urbanized BioTechia			
Calories/person/day	3,500 Kcal for top 5%; 2,200 Kcal for bottom 95%		Divergence in living standards between wealthy, poor
Food calories/acre	1.08 million for top 5%; 1.6 million for bottom 95%		Wealthy eat more land-intensive diet (e.g., meat)
Transportation fuel mix (gallons)	Corn-based ethanol: 4,110,988,601 Coal-based synfuels: 133,574,100		2.6 million barrels fuel per day could be made with 475 million tons of coal per year (National Coal Council)
Electricity fuel mix (mwh filled by each fuel)	*Coal* *Oil* *Gas* *Nuclear* *Hydro* *Wind* *Wood*	18,440,909 0 69,019 0 470,189 17,254,652 4,313,663	According to the scenario logic, only resources from the Midwest can be used, so no nuclear or oil fuels are available. Most electricity for the bottom 95% of the populace is from wind and wood.
Home heating fuel mix (mmbtu)	*Coal* 0 *Natural Gas* *Wood* *Diesel* *LPG*	*0* 28,506,903 168,724,751 0 0	Wealthy 5% heat their homes with natural gas; 95% heat their homes with wood.
Pandemic Collapse			
Population in Minnesota	3,695,081		Approximately 30% of population lost to pandemic (roughly equivalent to medieval Black Plague)
Average water consumption per person	Water use is severely limited; confined to surface water and rural wells.		
Industrial water use	0		Collapse of industry
Electricity demand/person	0		Population flee their homes; electricity use negligible
Vehicle miles/person/year	0		See above
Home heating demand/person/year	Nepal's level of wood fuel consumption assumed at 14.11 GJ/person/year in 2003		World Bank
Calories/person/day	2,000		Subsistence diet
Food calories/acre	663,636		Estimated based on vegetarian subsistence diet
Home heating fuel mix (mmbtu)	52,137,589		See above
Forest area lost/year	295,063 acres		See above

Appendix C. Model Structure.

Land Use

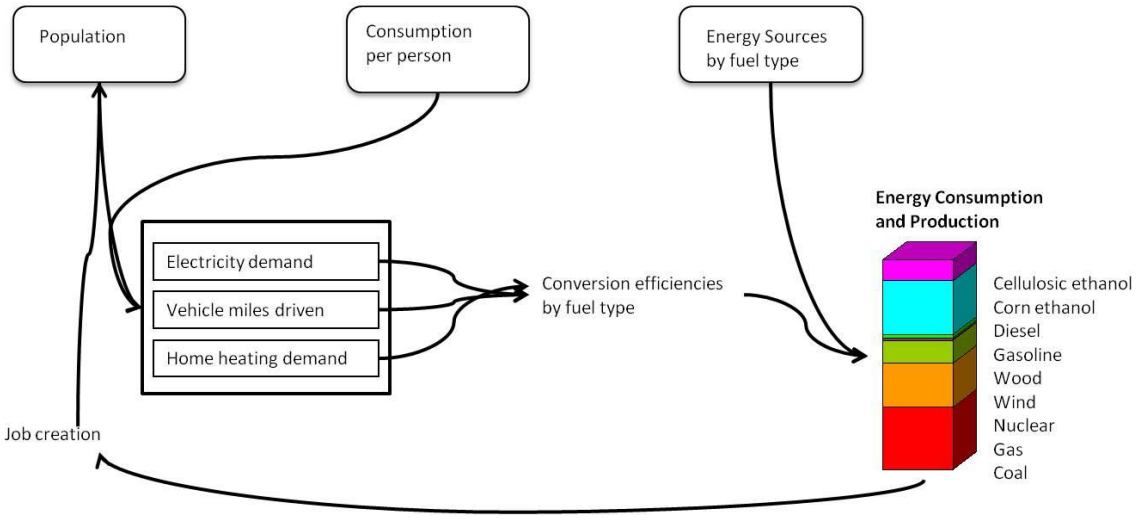


Water Consumption



Appendix C. *Cont.*

Energy



Appendix D. Input Sheet for Participatory Modeling during Statewide Workshop.

Population in 2050	
	people

Scenario Name?

Electricity Use per Person	
0.00	**mwh/person annually**

Vehicle miles traveled per Person	
0	**miles/person annually**

Average Fuel Economy for Cars	
0.00	**miles per gallon**

Blending Requirements	
0	**% Gasoline is Ethanol**
0	**% Diesel is Biodiesel**

Heating fuels per capita/year	
30	mbtu

Heating Fuels Mix		**%**
Wood		0
Natural Gas		0
Geothermal		0
	Total	100

Electricity Mix	**2050**	**%**
Coal		0.00
Gas		0.00
Nuclear		0.00
Hydro		0.00
Wind		0.00
MSW		0.00
Wood		0.00
Wave Generation		0.00
Solar		0.00
	Total	***100***

Note: greater than 100% means MN will produce electricity for export

Transportation Mix Personal Vehicles	**2050**	**% Miles**
Car		0
Bus		0
Motorcycle		0
Bullet Train		0
Hydrogen Fuel Cell Vehicle		0
Personal Rapid Transit		0
	Total	100

Appendix D. *Cont.*

Ethanol Source		%
Corn		0
Cellulosic Wood		0
Cellulosic Grasses		0
	Total	100

Note: greater than 100% means production for export

.

Biodiesel Source		%
Soy		0
Algae		0
	Total	100

Note: greater than 100% means production for export.

% Ag. Produced in State?	
0.00	

Note: greater than 100% means agricultural export.

Agricultural Production: Diet	
Subsistence	0
Or Wealthy	1

Water use per household	
0	**gallons daily**

Industrial Growth Relative to 2005	
0	**%**