Potential Contributions of Biomass Toward Sustainable Energy

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Global and Detailed Overview

- Energy Industry (10 km)
- Biomass Resource Characteristics (3 km)
- Overview of Technical Issues (1 m)
- Fuel Conversion Issues (1 mm)
- Desirable process characteristics (3 km)
- Conclusions (40 Mm)
Combustion fraction of total energy (85%)

Source: Energy Information Administration, Annual Energy Review 2001
Units in Quads
International Energy Supplies

Combustion Fraction of Energy Consumption

- OECD
- Non OECD
- OPEC
- EU
- IEA
- World Total

Year: 1990 to 2001

Combustion Fraction of Energy Consumption:
- OECD (■)
- Non OECD (▲)
- OPEC (▲)
- EU (▲)
- IEA (▲)
- World Total (▲)

Graph showing the combustion fraction of energy consumption for different regions and the world total from 1990 to 2001.
Energy and Economy

(linear correlation coefficient = 0.95)
Environmental Impacts

Comparison of Growth Areas and Emissions

- Gross Domestic Product
- Vehicle Miles Traveled
- Energy Consumption
- U.S. Population
- Aggregate Emissions (Six Principal Pollutants)
Impacts Quantified

- Resource Depletion
- Climate change
- Health Impacts

den Uil et al., 2002
Impacts Quantified

- Smog, Haze, VOCs, etc.
- Acid Rain, etc.
- Water Pollution, etc.

den Uil et al., 2002
US CO₂ Emissions

Coal Facts and Figures:
- 1 Billion Tons of Coal Consumed
- Coal generates 54% of US Electricity
- ~ 1200 Coal-Fired Power Plants

- Transportation 32%
- Electric Coal 30%
- Industrial 21%
- Other 13%
- Electric Other 4%

15% of Coal Emissions
Biomass Availability

- Wood waste: logging residues, sawdust, nonrecyclable paper
- Crop residues: wheat/rice straw, bagasse, almond shells
- Energy crops: poplar, switchgrass, willow

18.7 Quads of Coal
Potential Biomass Contribution

Carbon Emissions
(10^6 metric tons)

Year


Status Quo

Cofiring Scenario

Kyoto Protocol
Cofiring Reduces Net CO₂ Emissions

Graph showing the relationship between efficiency multiplier and effective reduction in CO₂ emissions. The graph compares current technology to future technology, highlighting the thermodynamic limit and 100% efficient power plant efficiency.
Biomass Energy Economics

Typical Cost of Energy from Conventional Co-firing Combustion

Cost of Electricity compared to feedstock prices, with various conditions, incentives, or subsidies.

Switchgrass COE Under Various Scenarios ($/kWh):

- COE w/ SO2 Credit and PTC
- COE w/ SO2 Credit, PTC, and Lost Ash Sales
- COE w/o Incentives
- COE w/ SO2 Credit (values not shown)
- COE w/o Incentives and Lost Ash Sales

PTC – proposed production tax credit incentive, e.g., Green Pricing Premium

Acknowledgement: Graph provided by Antares Group Inc
Biomass Cofiring Best Uses Resource

Cofired Units (demonstration and optimized)

Dedicated Unit Increasing Size

Efficiency/Coal Efficiency

10 MWe

60 MWe
2-4% of US oil supply could be offset from forest process industry residues.
Typical Fuel Properties

- **Dry Heating Value:**
  - Biomass: ~16 MJ/kg
  - Coal: ~25 MJ/kg

- **Volatile Matter:**
  - Biomass: 80% +
  - Coal: 40% +

- **Particle Size:**
  - Coal: ~100 µm
  - Biomass: ~3 mm
Elemental Compositions Differ

**COAL:**
- Black Thunder
- Pittsburgh #8

**BIOMASS:**
- Imperial Wheat Straw
- Red Oak Wood Chips

Legend:
- **C**
- **H**
- **N**
- **S**
- **Cl**
- **Ash**
- **O (diff)**
Ash Compositions Differ

**COAL:**
- Black Thunder: 7.2% Ash
- Pittsburgh #8: 7.8% Ash

**BIOMASS:**
- Imperial Wheat Straw: 15.4% Ash
- Red Oak: 1.3% Ash

SiO₂, Al₂O₃, TiO₂, Fe₂O₃, CaO, MgO, Na₂O, P₂O₅, K₂O, SO₃, Cl
Commercial Fuel Mix Varies

Woodland Fuel Mix, Spring-Summer 1993

- Eucalyptus
- Almond
- Coffee
- Mich Cal
- Pit Mix
- Pits
- Sawdust
- Shells
- Prunings
- Pine Dust
- WEYCO
- White Pine
- UWW
No Unusual NO$_x$ Synergies
Alfalfa Generates NH$_3$
NO\textsubscript{x} Behavior Complex (No Surprises)

NO

NH\textsubscript{3}  Straw ($\phi = 0.6$)  Coal ($\phi = 0.9$)  70:30 Straw:Coal ($\phi = 0.9$)
Stoichiometry and Temperature Impacts

Normalized NO\textsubscript{x} (both dry at 3% O\textsubscript{2})

Nominal Reburn Zone Equivalence Ratio

- 900°C, 250 ppm
- 1200°C, 500 ppm
- 900°C, 500 ppm
- 1200°C, 250 ppm
Cofiring Deposition
Deposition Rates Vary Widely

- Cofiring biomass can lead to either decrease or increase in deposition rates.
- Cofiring decreases deposition relative to neat fuels.
Commercial Stoker Systems:

- Fuel Bin
- Stoker
- Grate
- Overfire Air
- Stokers
- Slag Screen
- Secondary Superheater
- Primary Superheater
- Boiler Generator Bank
Deposits Dissimilar to Fuel

![Graph showing mass percent of various elements in fuel and ceiling/corner deposits.](image)

- **SiO2**
- **Al2O3**
- **TiO2**
- **Fe2O3**
- **CaO**
- **MgO**
- **Na2O**
- **K2O**
- **P2O5**
- **SO3**

**Legend:**
- **Fuel**
- **Ceiling/Corner Deposit**
Composition Maps Support Corrosion Hypothesis

100% Imperial Wheat Straw

85% E. Kentucky  15% Wheat Straw
Fuel Properties Predict Corrosion
Oxygen Isosurfaces
Striations in T-fired Units
Vapor deposition

Vapor deposition flux [g/m²/h]
Strength

Compression test

Day

Cement
Class C
Class F
SW1
SW2
Wood
Wood C
Wood F
RGB Camera Performance

Spectral Responsivity [(DN)/(nJ/cm²)] vs. Wavelength (micron)

- Red
- Green (R)
- Green (B)
- Blue
Optical Signal Validation

![Graph showing the relationship between experimental temperature (T_exp, K) and calculated temperature (T_calculated, K). The graph is a scatter plot with a linear trend line.](image-url)
Optical Signal Validation

![Graph showing the relationship between Blackbody Temperature and Calculated Temperature. The graph is a linear plot with the calculated temperature increasing as the blackbody temperature increases. The data points are marked with diamonds and the trend line is represented by a magenta line. The x-axis represents Blackbody Temperature (K) ranging from 800 to 1500, and the y-axis represents Calculated Temperature (K) ranging from 800 to 1500.]

- Blackbody Temperature, K
- Calculated temperature
- Blackbody temperature
Surface Temperature & Emissivity

Devolatilization

Char burning (0.26 s later)

Measurable range (1000-1800 K), -40 ~ 80 K uncertainty
Initial nominal diameter = 3 mm
Typical Mass/Temperature Data
Shape Impacts

Mass Loss, $1 - \frac{m}{m_0}$

- Plate (exp.)
- Plate (model)
- Cylinder (model)
- Cylinder (exp.)
- Near-sphere (exp.)
- Near-sphere (model)

in N$_2$

d = 11 mm.
Impacts on Conversion Time

AR=5.0, in N2
- Near-sphere/Plate, exp
- Cylinder/Plate, exp
- Plate/Plate
- Near-sphere/Plate, model
- Cylinder/Plate, model

Conversion Time Ratio vs. Equivalent Diameter, mm
Impacts on Conversion Time

AR=8, in N2

Conversion Time Ratio vs. Equivalent Diameter, mm

- near-spherical/plate - exp.
- cylinder/plate - exp.
- plate/plate
- near-spherical/plate - model
- cylinder/plate-model
- plate/plate
Impacts on Temperature

d=11mm in N₂
Tw=1373 K
Tg=1050 K
In Situ Experimental Data
Chlorine Controls Aerosol Amount

- 0.12% Cl, 0.17% Alkali
- 0.16% Cl, 0.25% Alkali
- 0.01% Cl, 0.09% Alkali
- 0.01% Cl, 0.48% Alkali

Chenevert
High-chlorine Aerosol Composition

- Cl: 45%
- Si: 13%
- Na: 17%
- K: 14%
- S: 2%
- Al: 5%
- Ca: 4%

Chenevert
Low-chlorine Aerosol Composition

- Si: 45%
- Ca: 20%
- Al: 12%
- Na: 6%
- Mg: 3%
- K: 9%
- S: 5%

Chenevert
Basic Compounds Poison Catalysts

Catalyst Activity vs. Na Poison Amount

Activity (k/k₀) vs. Poison Ratio (Na:V)

BYU wet
BYU dry
Chen et al.

NO Conversion

M1 Catalyst
  ++ Fresh
  + + Fresh Fit
  ○ Exposed 2063 hr
  ● Exposed 3800 hr
  + + + Exposed 2063 hr Fit
  + + + Exposed 3800 hr Fit

K, cm³/g*s

Temp, K

24-hour sulfated
A = 28527 +/- 18400
Ea = 34737 +/- 2920

Light sulfated
A = 27045 +/- 7580
Ea = 34556 +/- 1270

Fresh
A = 17736 +/- 21500
Ea = 34640 +/- 5720

CI_24HSK
CI_KF
Ultimate Best Practices Attributes

• Use of residues
• Integration in existing industry
• Production of fungible product
• Broad opportunity
• Focus on objective (climate change, sustainable energy, energy security, etc.)
Bottom-line Conclusions

• Any solution to the global climate change problem involves all of the following:
  • All practical renewable energy options
  • Storage and capture
  • Substantial increase in nuclear power
  • Substantial change in lifestyle in developed world
Australia is the Key
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