The Niche for Small Residual Biomass Plants

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The Minnesota Futurists
Minneapolis, 23 February 2008

Problem: Global Warming and Energy Dependence

- Global warming is a fact
- Its relation to man-made CO2 emissions has been accepted
- The US imports about 1/3 of its total energy needs of ~ 110 quad Btu/year

Solution: Switch to (nuclear &) renewable energy

- The US only uses 1/10 renewable energy now
- Solar PV energy could supply total US energy needs of ~ 110 quad Btu/year on ~ 1% of its area, and yield 70x more W/acre than biofuels
- But bio-fuel ROI is ~24x higher than solar PV

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Envisioned Small BioFuels Plant

This is not:

- Starch conversion and fermentation
- Cellulosic biomass partial hydrolysis and fermentation to ethanol
- Biomass pyrolysis (Energy Conversion Technologies, Windsor Ontario)
- Biomass / municipal waste plasma gasification (Startech Plasma)

But:

- Biomass gasification to producer gas >> syngas >> GTL conversion,
  - Using steam-based gasification – direct or indirect?
  - Permeation, sieving or solvation ?? of syngas cleanup, and
  - Catalytic reaction to HC (Fe), ethanol (Ru) or methanol (Cu)

The challenge: Prove its technical and economic viability

Could we afford automobiles if each had to be custom-assembled in our back yard?

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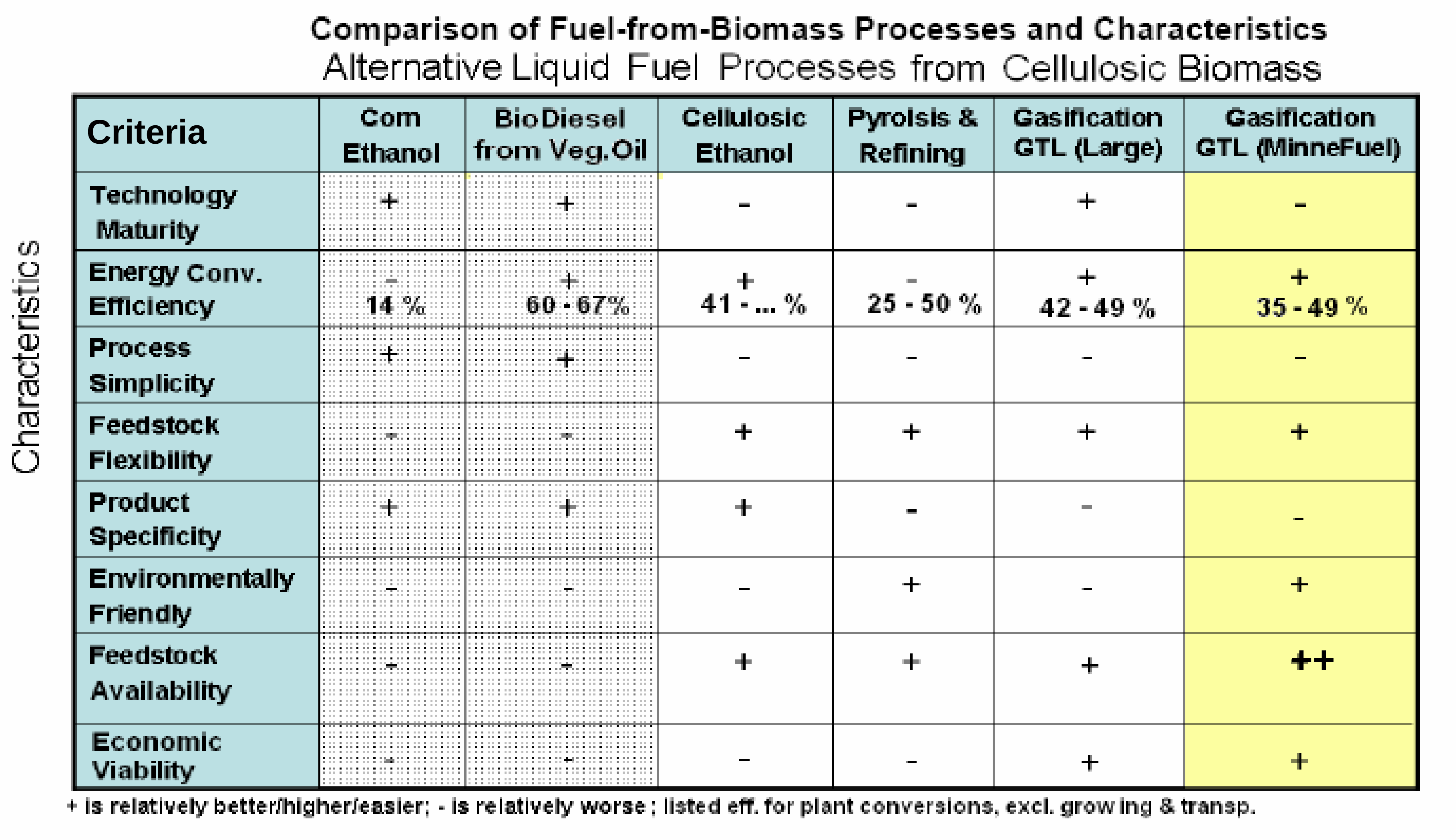

Comparison of Fuel-from-Biomass Processes and Characteristics

Alternative Liquid Fuel Processes from Cellulosic Biomass

Characteristics

Criteria	Corn Ethanol	BioDiesel from Veg.Oil	Cellulosic Ethanol	Pyrolsis & Refining	Gasification GTL (Large)	Gasification GTL (MinneFuel)
Technology Maturity	+	+	-	-	+	-
Energy Conv. Efficiency	- 14 %	+ 60 - 67%	+ 41 - ... %	- 25 - 50 %	+ 42 - 49 %	+ 35 - 49 %
Process Simplicity	+	+	-	-	-	-
Feedstock Flexibility	-	-	+	+	+	+
Product Specificity	+	+	+	-	-	-
Environmentally Friendly	-	-	-	+	-	+
Feedstock Availability	-	-	+	+	+	++
Economic Viability	-	-	-	-	+	+

+ is relatively better/higher/easier; - is relatively worse ; listed eff. for plant conversions, excl. growing & transp.

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Advantages of Small vs. Large Plants

- **Cost saving from "factory assembly" vs. “field assembly”**
- **Cost saving via "learning curve" from continuous improvement of mass production**
- **Have access to lower-cost, local and distributed feed-stock, and benefit of shorter transport distances**
- **Lower-cost distribution (no middlemen)**
- **Mobile, no hook-ups needed to electric, water or sewer**
- **Provide jobs to local economy**
- **Less noise and local traffic congestion by large trucks hauling low-density biomass**
- **Lower cost of burdened labor**
- **Lower-cost air and water pollution control systems***

* For example, EPA stack emission limits of NOx, SOx and PM from utility plant boilers were at first only mandated for plants with outputs over 250 MWe, with impact on kWh “product” of about 5-10%. Limits for small boilers were mandated later as appropriate, when lower-cost technology became available.

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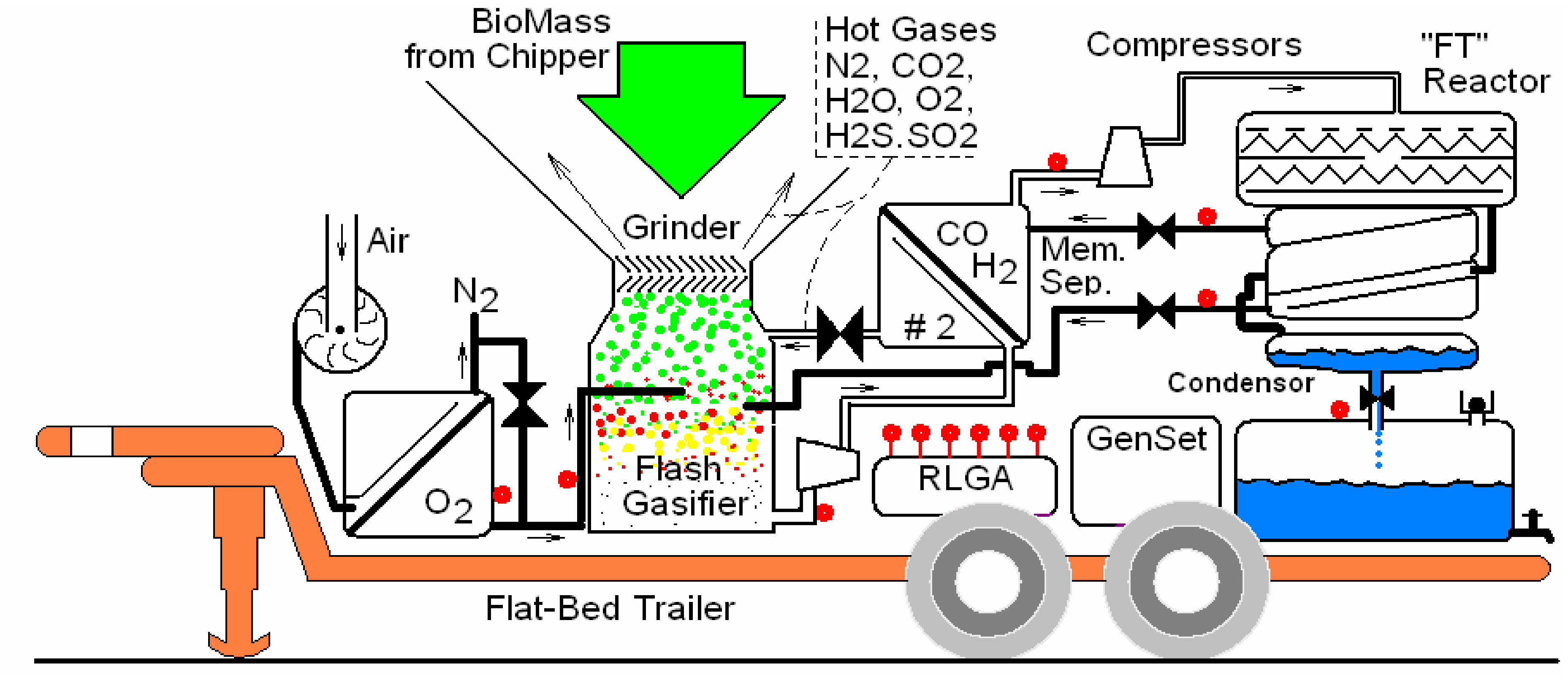
Envisioned Small BioFuels Plant (Forestry/Farm Scale), Rev.3



The ● are gas sampling points, connected to ports of a ● gas analyzer, such as the RLGA = Raman Laser Gas Analyzer by ARI.

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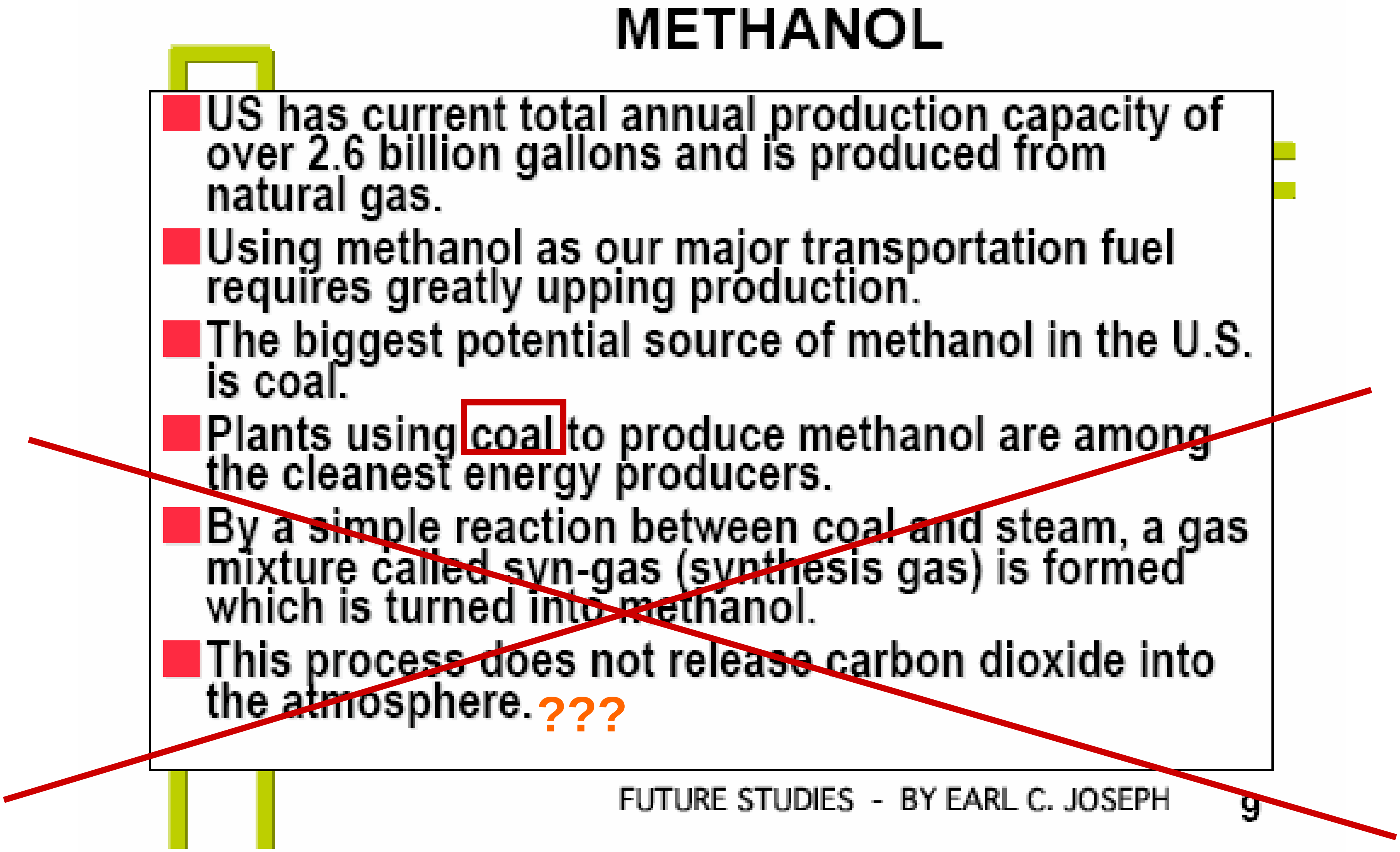
ALTERNATIVE ENERGY FUTURES 1/18/06 by Earl C. Joseph & Hank Lederer

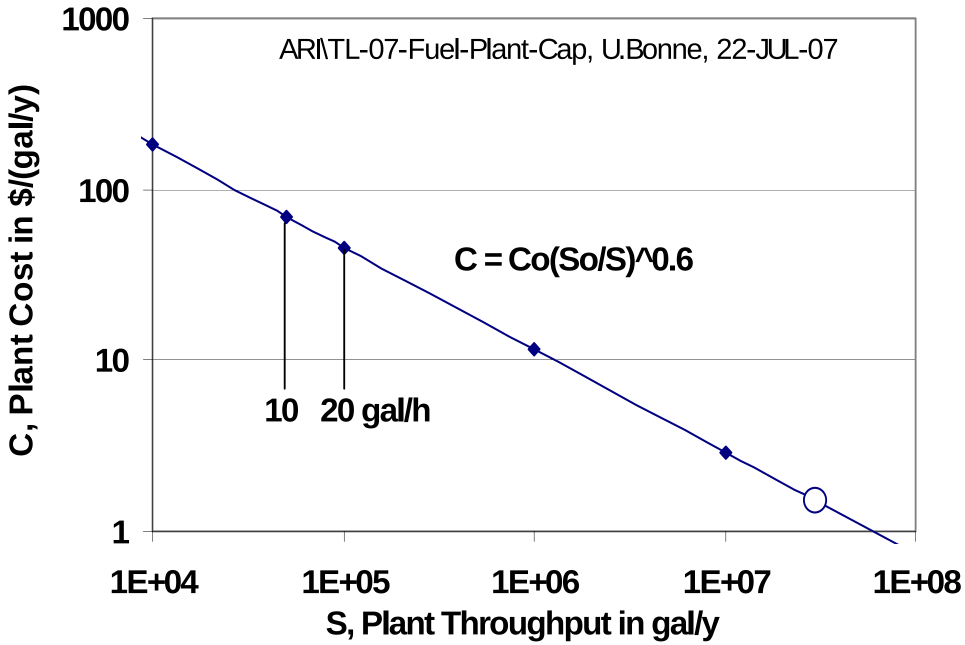


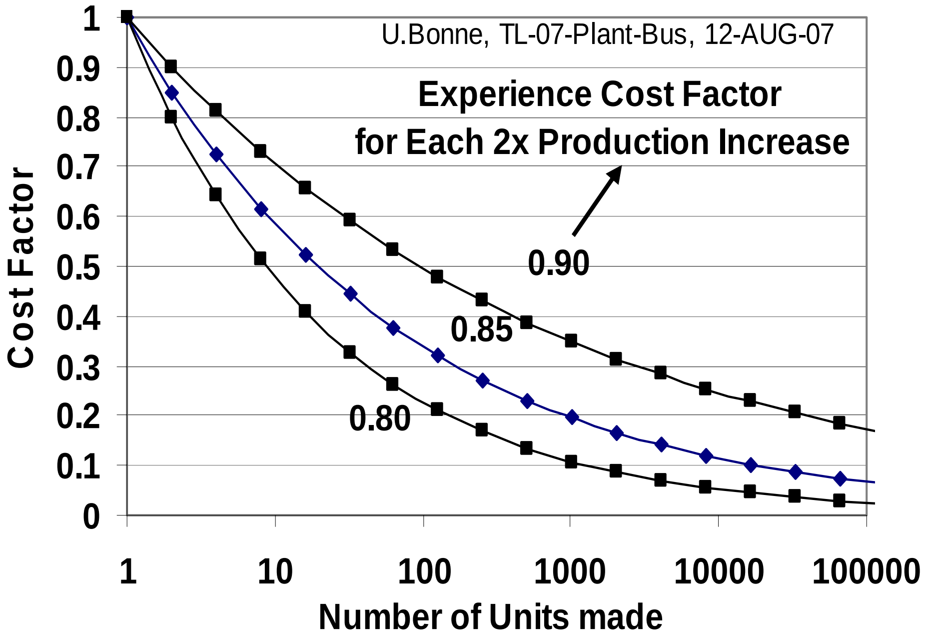
METHANOL

- US has current total annual production capacity of over 2.6 billion gallons and is produced from natural gas.
- Using methanol as our major transportation fuel requires greatly upping production.
- The biggest potential source of methanol in the U.S. is coal.
- Plants using coal to produce methanol are among the cleanest energy producers.
- By a simple reaction between coal and steam, a gas mixture called syn-gas (synthesis gas) is formed which is turned into methanol.
- This process does not release carbon dioxide into the atmosphere. ???

FUTURE STUDIES - BY EARL C. JOSEPH 9

Compare Economies of Scale: 1. Size vs. 2. Volume





1. **Economies of scale are obtained as plant sizes increase. The shown empirical relation is also used to keep plant costs low in terms of $ per installed capacity via process intensification, see** M.V.Koch, K.M.VandenBussche and R.Crisman, “Micro Instrumentation for High Throughput Experimentation and Process Intensification,” Wiley-VCH, Weinheim, Germany (2007) p.50, Fig.3.5
2. **High volume production reduces cost via “Learning Curve/Experience Factor”:** a. http://cost.jsc.nasa.gov/learn.html

   b. Stephen R. Lawrence http://leeds-faculty.colorado.edu/lawrence/Tools/Learn/LTheory.htm

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Labor and Burden Costs vs. Company Size

Hypothesis: Large company labor+burden rate is higher than with small companies. Why?

Assumptions: Wealth producing workers are 1st level production, engineering, maintenance, who support (with their overhead) all layers above them Linear simple model: 5x fewer mgrs. in each successive layer, but they earn 2.6x more

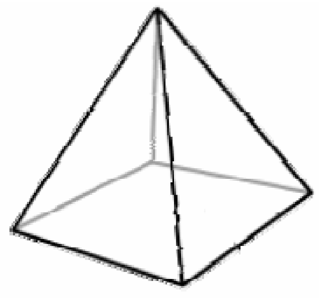
n	$\frac{S_n}{S_{n-1}}$	$\frac{N_n}{N_{n-1}}$	$\frac{N_t}{N_1}$	$\frac{C(1\ell)}{C(1s)}$
2	2.6	0.196	1.24	1.51
3	2.6	0.196	1.24	1.77
7	2.6	0.196	1.24	2.02

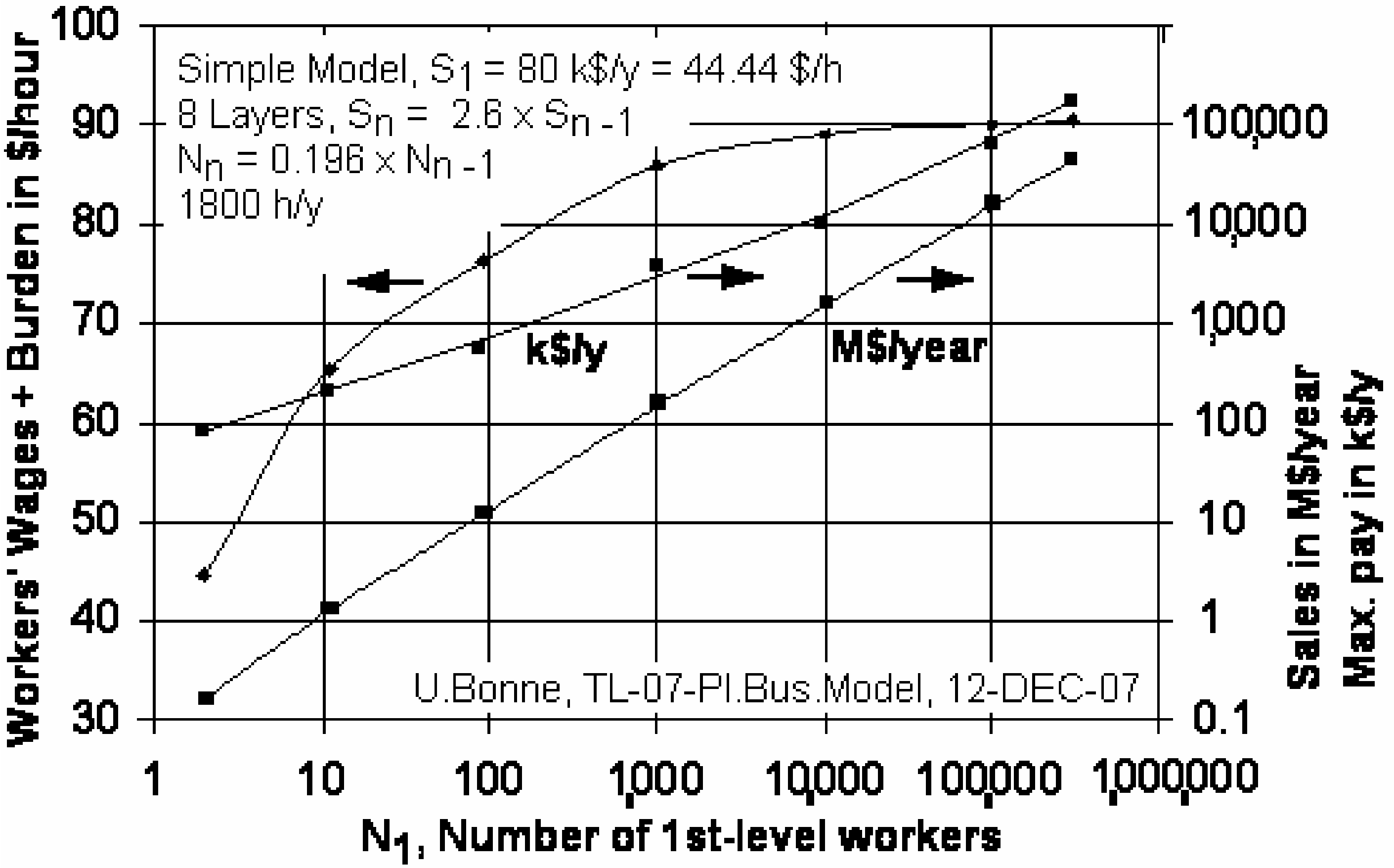
n = number mgmt.layers

N = num. of employees

S = Salary

C = L+B ratio of 1^{st} level





Wages and sales vs. number of 1st-level workers

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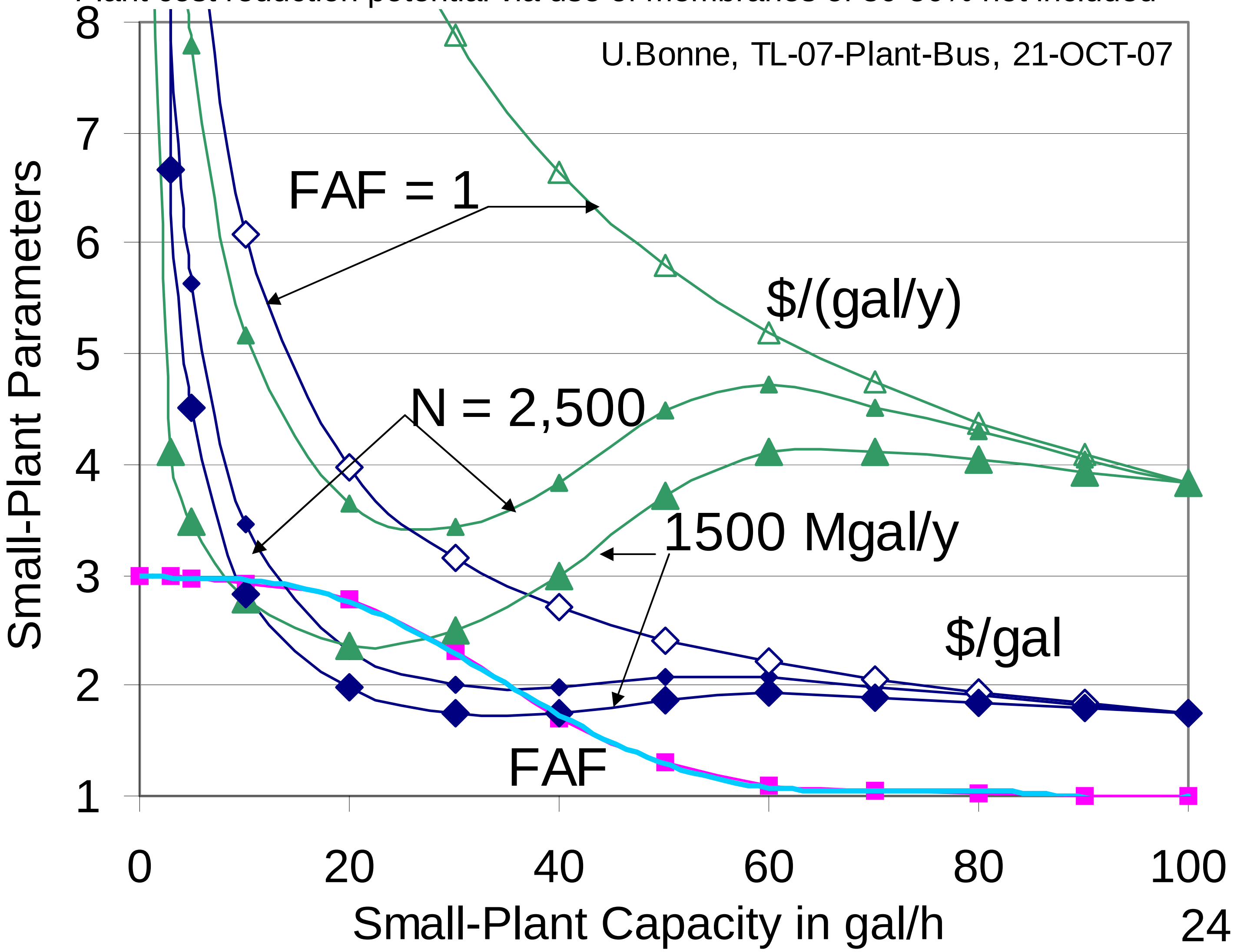
Plant and Product Cost vs. Size & F.Assembl.Factor

for constant # small plants or const. total production

Plant cost reduction potential via use of membranes of 30-50% not included



U.Bonne, TL-07-Plant-Bus, 21-OCT-07

2007 Consumption

in billion gal/y:

US Gasoline – 141

MN Gasoline – 2.8

~ 2.0%

Population: 5.2/300

~ 1.7%

24 tons/day input

MinneFuel, LLC

Ref.: 30 Mgal/y = 3,750 gal/h

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Modeled Small Plant Economic Feasibility:150Plants

	BTL BUSINESS MODEL TO COMPUTE PLANT & FUEL COST IN $/(GAL/Y) & $/GAL. SMALL PLANTS							
	INPUTS				OUTPUTS		In	Out
3	Capacity in gal/h	25		3	Ref./Small Plant size ratio	150	Q	R
4	Up-Time in h/year	6000		4	Mass prod.cost saving factor	0.0857	t	Sm
5	Ref. Plant size in gal/y	30,000,000		5	**BM plant cost in $/(gal/y)**	**1.924**	Qr	C
6	Ref. Plant cost in $/(gal/y)	3		6	BM plant cost in $	384,832	Cr	Cc
7	Land cost in $/acre	4500		7	Payment w/interest per $/year	77,468	Ca	
8	Production of plants in #/y	9,330		8	BM feedsock in tons/y	1762	N	F
9	Fcty assembly saving factor	2.7		9	in lbs/h	587	Sf	Fh
10	Years to pay loan in years	8		10	in dense ft3/y	320,315	tL	Fv
11	Interest on loan in %/y	12		11	Yield in gal/ton (for listed % Eff)	85.1	r	Yw
12	Profit in % of fuel sales	10		12	Total cost feedstk & prd.trans.,$/ton	7.43	P	Cw
13	Economy of plant scale, power	0.6		13	Number of people to run plant/shift	0.497	n	Hu
14	Learning curve in %/doublg.	83		14	Cost of ethanol in $/gal - feedstk	0.0872	L	VF
15	BM feedst.cost in $/ton	0		15	- Plant labor ~(Q/Qr)^0.63/3, $/gal	0.5959	Cf	VL
16	Include BM transp.cost: 0=N,1=Y	1		16	- amortization in $/gal	0.5165	Ct	VC
17	Plant op.labor cost in $/h/shift	30		17	- profit in $/gal	0.1200	CL	VP
18	BM harvest in tons/acre	3.5		18	- maintenance, insur'ce, prp.tax	0.0185	Ya	Vm
19	Distribution in % of mfct. cost	20		19	- distribution	0.2676	Cd	Vd
					Total in $/gal	**1.6057**		V
21	BM energy conv.eff in %	35		21	- incl. BioMax25 Electr. $/kWh	0.0251	ηE	Ve
22	BM LHV in Btu/lb	9200		22	Total ethanol produced, million gal/y	1399.5	Hb	
23	Ethanol LHV in Btu/gal	75,637		23	Total manufactg. assets in $	7,180,970,891	He	CT
24	Ethanol density in lb/gal	6.549		24	Total number plants needed	1,072,808	ρe	Ns
25	All US waste BM, bill tons/y	1.89		25	Years to achieve 25% saturation	29	Y	t20
	Density of pell.stover in lb/ft3	11		26	Total US potential in bill.gal eth/y	161	ρ	Yb
27				27	CO2 emiss. redution of total E in %	11.8		ΔE
28	Num.Small MN plants in oper'n.	30,000		28	CO2 em.redution of gasoline E in %	35.5	n	ΔEt
29	MN factory labor value add in %	30		29	Total cost of the loan in $	619,743	Va	Ct
30	MN factory labor cost in $/h	50		30	MN BM feedstock in million tons/y	52.9	Cf	Fa
	MN factory indiv.labor h/year	2000		31	MN fuel production in billion gal/y	4.50	tf	Qmn
32				32	MN fuel gross revenue in B$/y	7.23		Sf
33	Cost of truck fuel in $/gal	3		33	MN factory(val.added)sales in B$/y	3.59	Cg	Sa
34	Time to load and unload BM, h	1		34	MN jobs - Fuel prod. + distribution	33,000	tf	Je
35	Truck BM capacity in tons	5		35	- Plant product.+ servcg.in $/y	35,905	L	Jm
36	Trucking cost prod./feedst., ratio	0.1		36	- Average gross pay/SP-job in $/y	90,000	Rpf	Pe
37	Truck cost + 50% interest in $	110,000		37	3xMax.radial BM-plant dist. in miles	1.51	Cm	ds
38	Truck life in miles	200,000		38	Truck average speed in miles/h	21.2	Z	v
39	Truck SP average speed, miles/h	20		39	Cost of feedstock transport in $/ton	7.21	vo	Cw*
40	Truck mileage in miles/gal	4		40	Cost of product transport in $/ton	0.21	Ym	Cp
			TL-07-Plant-Business-Model, Rev. 8, U.Bonne, 5-Nov-07					

Not included is plant cost reduction potential of 30-50% via use of membranes

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Modeled Small Plant Economic Feasibility:150Plants

	SHORT COMPARISON OF LARGE AND SMALL PLANTS				
	Inputs	Large	Large	Small	Small
3	Capacity in gal/h	3750	3750	25	25
4	Up-Time in h/year	6000	6000	6000	6000
5	Ref. Plant size in million gal/y	30	30	30	30
6	Ref. Plant cost in $/(gal/y)	3	3	3	3
7	Land cost in $/acre	4500	4500	4500	4500
8	Production of plants in #/y	1	1	150	2,000
9	Fcty assembly saving factor	1	1	2.7	2.7
10	Years to pay loan in years	8	8	8	8
11	Interest on loan in %/y	8	8	12	12
12	Profit in % of fuel sales	20	20	10	10
13	Economy of plant scale, power	0.6	0.6	0.6	0.6
14	Learning curve in %/doublg.	83	83	83	83
15	BM feedst.cost in $/ton	30	30	0	0
16	Include BM transp.cost: 0=N,1=Y	1	1	1	1
17	Plant op.labor cost in $/h/shift	50	50	30	30
18	BM harvest in tons/acre	3.5	3.5	3.5	3.5
19	Distribution in % of mfct. cost	80	64	20	20
20	Est. Cost of BioMax-25 kW, k$	250	250	65	32.4
	Outputs				
1	Plant capacity cost in $/(gal/y)	3	3	5.84	2.911
2	Fuel retail price in $/gal	3.288	2.996	2.993	1.955
3	Electrical energy cost in ¢/kWh	26.34	26.34	6.14	3.4

Not included is plant cost reduction potential of 30-50% via use of membranes

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Biomass Resources in Minnesota *

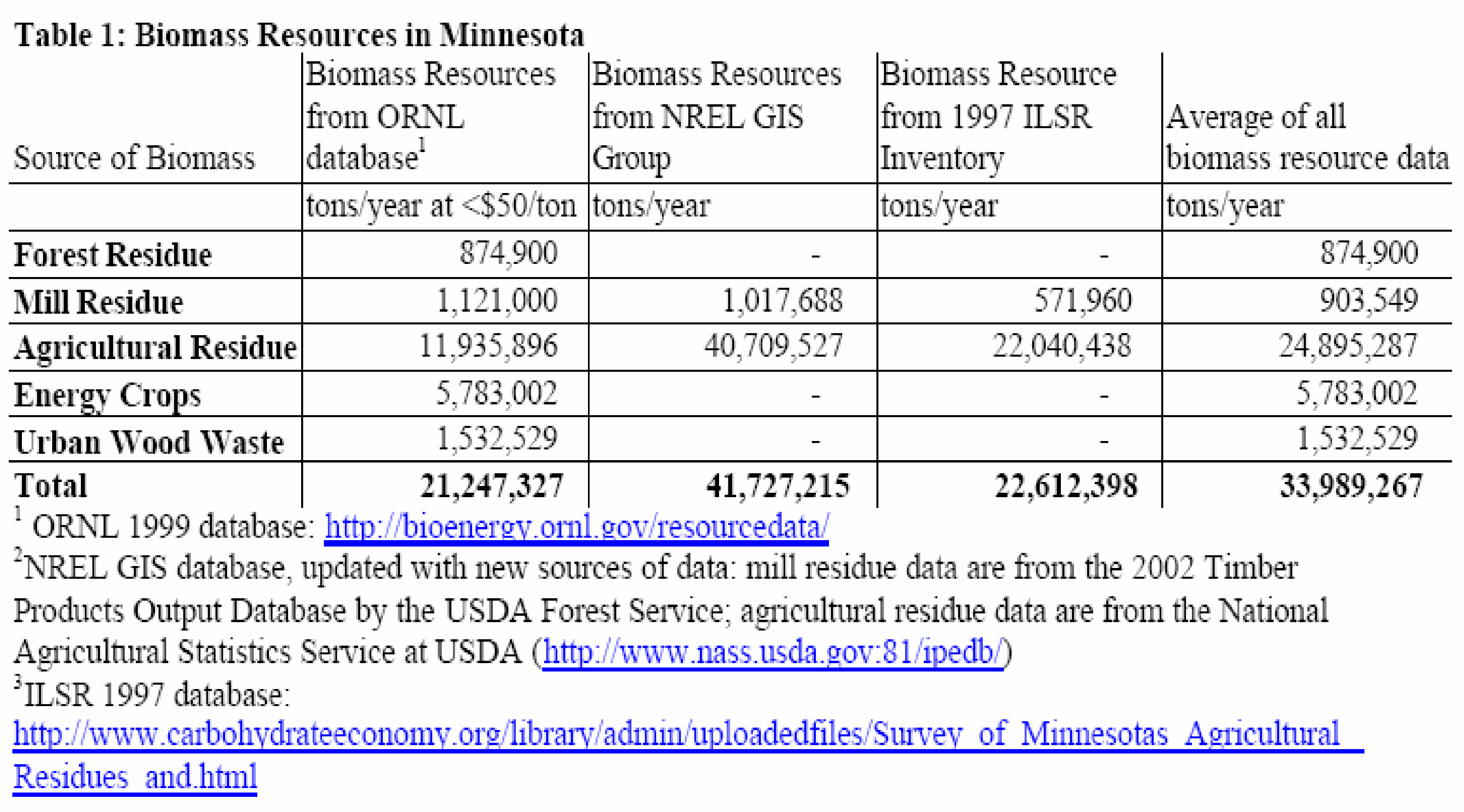


Table 1: Biomass Resources in Minnesota

Source of Biomass	Biomass Resources from ORNL database[1]	Biomass Resources from NREL GIS Group	Biomass Resource from 1997 ILSR Inventory	Average of all biomass resource data
	tons/year at <$50/ton	tons/year	tons/year	tons/year
Forest Residue	874,900	-	-	874,900
Mill Residue	1,121,000	1,017,688	571,960	903,549
Agricultural Residue	11,935,896	40,709,527	22,040,438	24,895,287
Energy Crops	5,783,002	-	-	5,783,002
Urban Wood Waste	1,532,529	-	-	1,532,529
Total	**21,247,327**	**41,727,215**	**22,612,398**	**33,989,267**

[1] ORNL 1999 database: http://bioenergy.ornl.gov/resourcedata/

[2] NREL GIS database, updated with new sources of data: mill residue data are from the 2002 Timber Products Output Database by the USDA Forest Service; agricultural residue data are from the National Agricultural Statistics Service at USDA (http://www.nass.usda.gov:81/ipedb/)

[3] ILSR 1997 database: http://www.carbohydrateeconomy.org/library/admin/uploadedfiles/Survey_of_Minnesotas_Agricultural_Residues_and.html

* http://www.pca.state.mn.us/oea/p2/forum/MNbiomass-NREL.pdf Feb. 2005

"Minnesota Biomass - Hydrogen and Electricity Generation Potential.
A study by the National Renewable Energy Laboratory," by NREL, Boulder, CO

Small Scale Universal Biomass Conversion Plants. Benefits for NE Minnesota, @ 25% Residual BM Use:

(8 mill acres corn + 6.5 mill acres SFI forests) x 3.5 tons/acre x 100 gal/ton >> 5.8 Bgal fuel. With production rate of 3,000 Plants/year & 30,000 Plants operating in Minn.x 25 gal/h >> 3.5 Bgal fuel/y. 2.8 Bgal MN use.

Revenue for NE-Minn small plant sales: 4.08 B$/y @ 400k$/ea

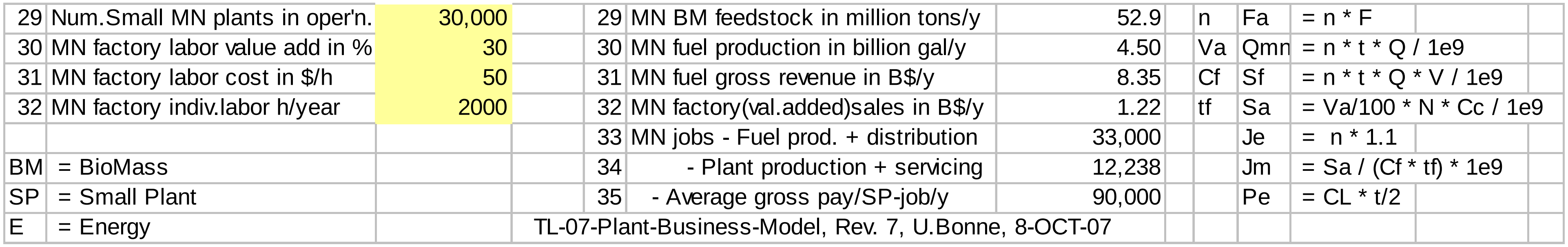
Revenue for Minn renewable eth. sales: 8.35 B$/y @ 1.85 $/gal

Factory Jobs NE-Minn: 12,000 jobs – plant product.& service

Small-Plant Jobs Minn: + 33,000 jobs – fuel product.& distrib.

Minn. gasoline fossil fuel displacement: 85%

Total fossil & CO2 emissions reduction: >30%. Details:



29	Num.Small MN plants in oper'n.	30,000		29	MN BM feedstock in million tons/y	52.9		n	Fa	= n * F		
30	MN factory labor value add in %	30		30	MN fuel production in billion gal/y	4.50		Va	Qmn	= n * t * Q / 1e9		
31	MN factory labor cost in $/h	50		31	MN fuel gross revenue in B$/y	8.35		Cf	Sf	= n * t * Q * V / 1e9		
32	MN factory indiv.labor h/year	2000		32	MN factory(val.added)sales in B$/y	1.22		tf	Sa	= Va/100 * N * Cc / 1e9		
				33	MN jobs - Fuel prod. + distribution	33,000			Je	= n * 1.1		
BM	= BioMass			34	- Plant production + servicing	12,238			Jm	= Sa / (Cf * tf) * 1e9		
SP	= Small Plant			35	- Average gross pay/SP-job/y	90,000			Pe	= CL * t/2		
E	= Energy		TL-07-Plant-Business-Model, Rev. 7, U.Bonne, 8-OCT-07									

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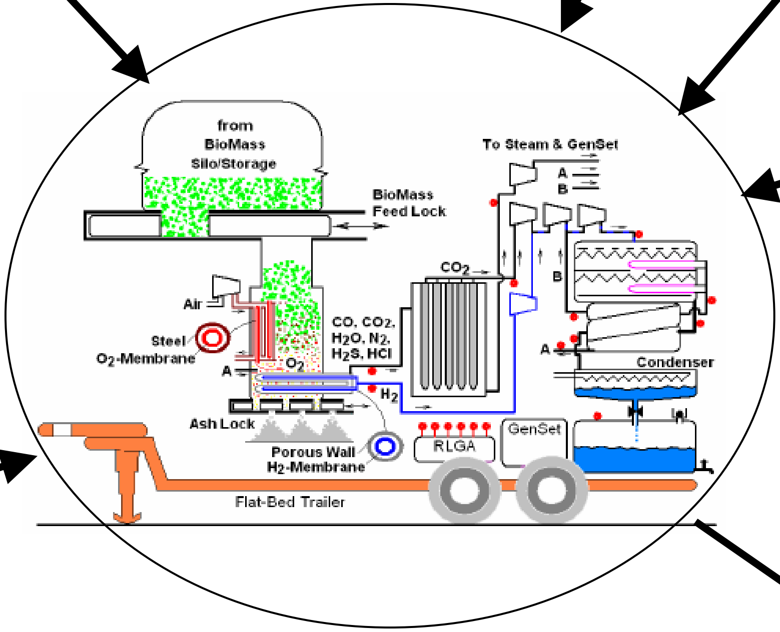
Components of Universal Biomass Conversion System

BioMass
Chipper &
Chip Storage



Selective
O2, H2,…
Membranes

FT Reactor &
Catalyst
Regeneration

ARI Gas Analyzer
& Control System

Fuel Product
Storage
and Distribution

**Unique Integration & Mass
Production of Small Systems
by ??? and MinneFuel**

MinneFuel, LLC

Developmental Equipment: Biomass Storage

168,000 ft^3 54.7 ft diam.

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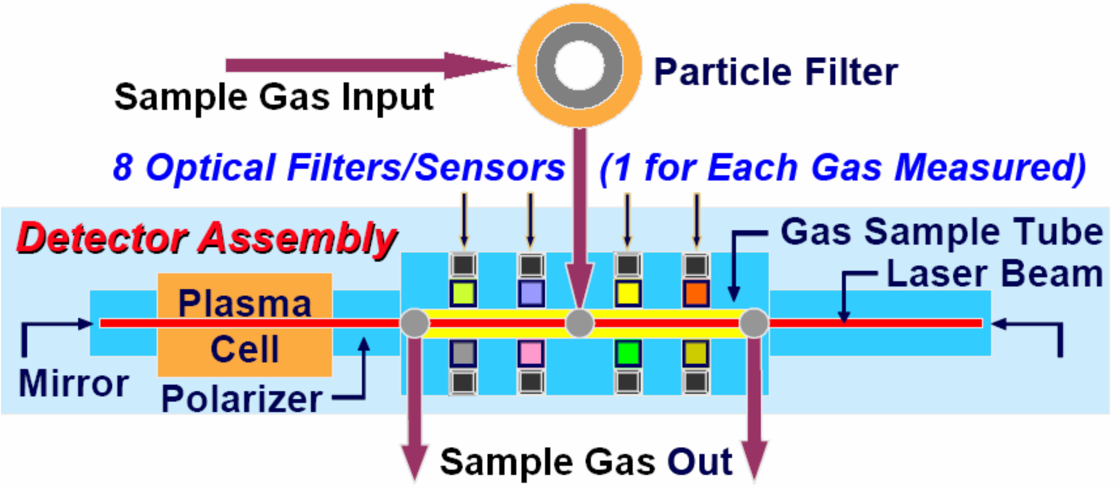
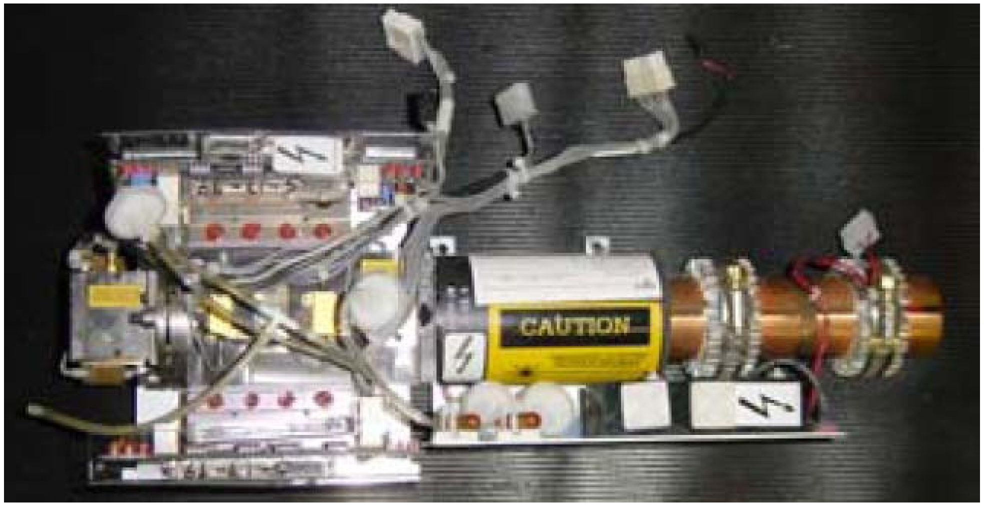
Available Equipment: ARI Raman Laser Gas Analyzer (RLGA) & Control, to Enable Efficient Plant Operation

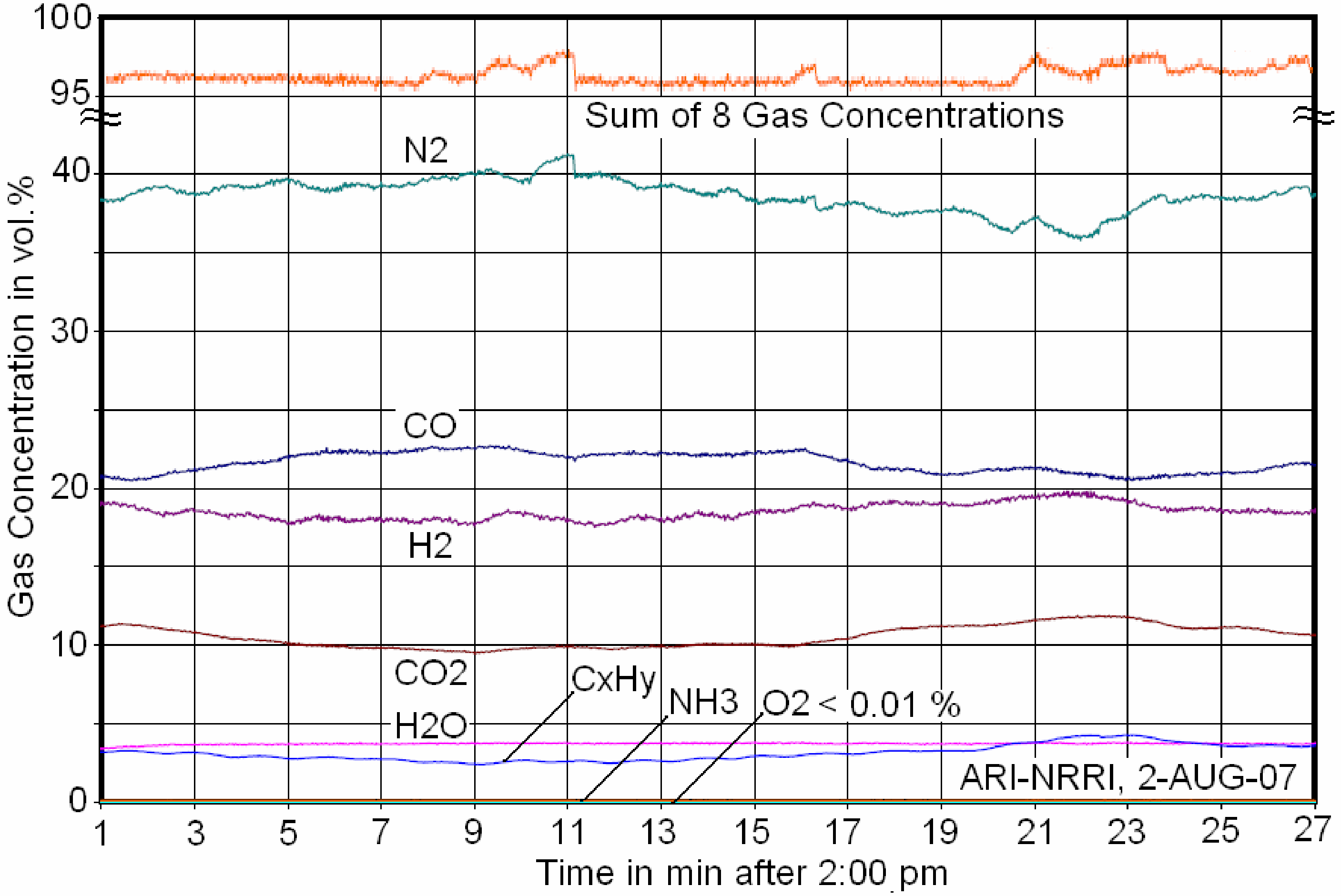

Sample Gas Input
Particle Filter
8 Optical Filters/Sensors (1 for Each Gas Measured)
Detector Assembly
Gas Sample Tube
Laser Beam
Plasma Cell
Mirror
Polarizer
Sample Gas Out

Gas Species	Lower Limit
Hydrogen - H_2	100 ppm
Nitrogen - N_2	50 ppm
Oxygen - O_2	50 ppm
Water Vapor - H_2O	10-50 ppm
Carbon Monoxide - CO	50 ppm
Carbon Dioxide - CO_2	25 ppm
Organics - C_xH_y	10-50 ppm
Ammonia - NH_3	10-50 ppm



The industrial RLGA can measure all gases important for biomass plant operation, e.g. H2, CO, CH4, CH3OH, C2H5OH, NH3, CO2, H2O, N2, O2, HCl, SO2, via sets of 8 gases from multiple ports, every 50 ms. Sample conditioning and self-cal included.

ARI Raman Laser Gas Analyzer (RLGA): Analysis of Wood Chip Gasification at NRRI



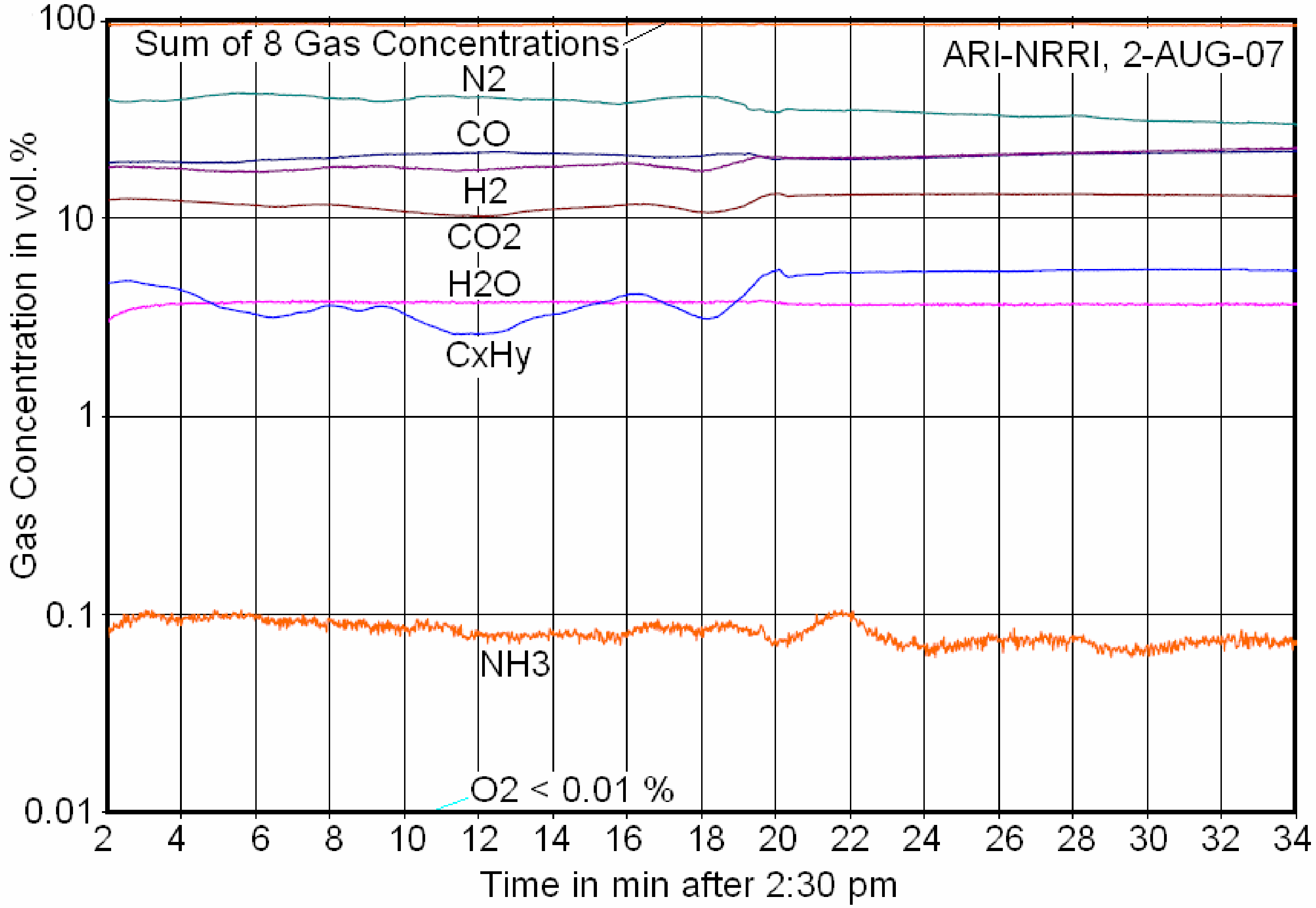
Biomass gasification test with a CPC BioMax-25 at NRRI, with a wood chip feed rate of 64 kg/h. Gas composition via ARI's 8-channel Raman LGA. The sum of the 8 measured gas conc. is <100% because H2S, HCL, Ar, P- and CHxOy gases were not included, but highlights the excellent performance of the LGA.

ATMOSPHERE RECOVERY, INC.
Precision Management of Process Gases

NATURAL RESOURCES RESEARCH INSTITUTE

Ron Rich – rrr@atmrcv.com

ARI Raman Laser Gas Analyzer (RLGA): Analysis of Wood Chip Gasification at NRRI



Biomass gasification test with a CPC BioMax-25 at NRRI, with a wood chip feed rate of 75 kg/h. Gas composition via ARI's 8-channel Raman LGA, showing high signal/noise and excellent sensitivity to NH3.

ATMOSPHERE RECOVERY, INC.
Precision Management of Process Gases

UMD DULUTH
NATURAL RESOURCES
RESEARCH INSTITUTE

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Operation/Design Parameters for 4 Plant Sizes

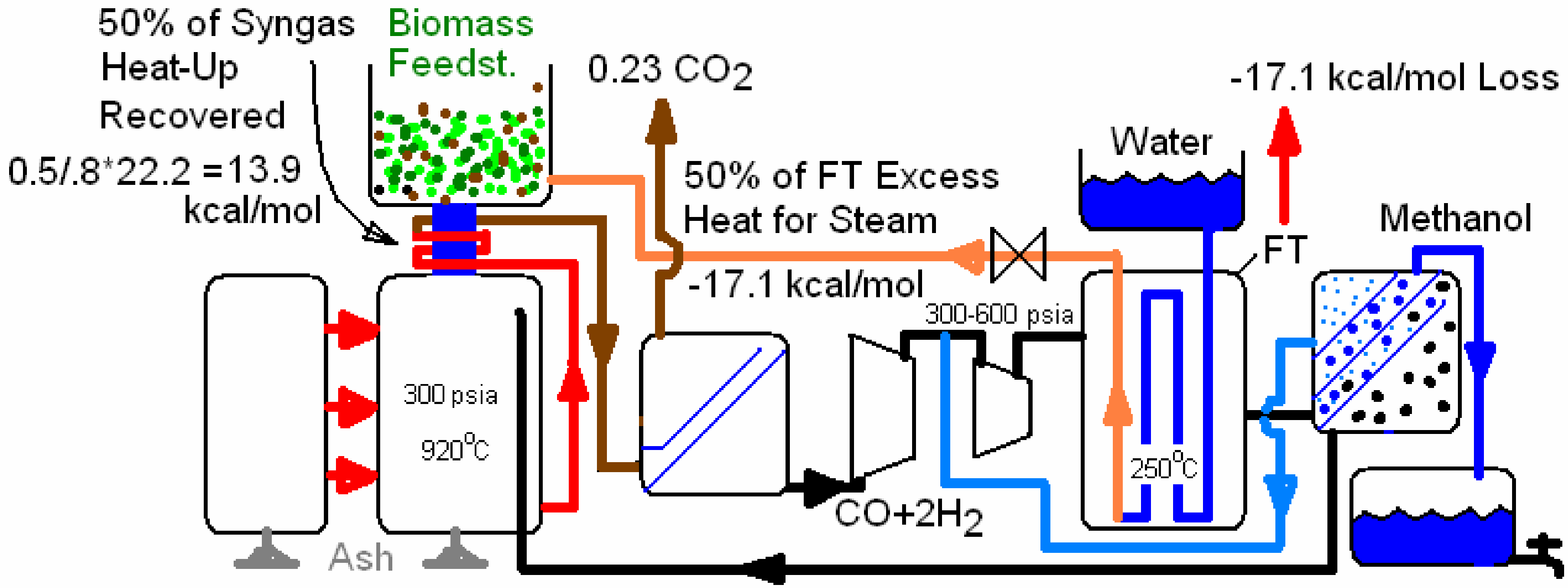
Cellulosic Biomass Conversion Plants (65% conversion)

Sizes		Desktop	Trailer	Coop	Central
Ethanol Output	in cm3/h	10			
	in gal/h	0.004	10	>610	
	in million gal/y		0.0876	>5.3	35 - 208
	in kg/h		29.7		
	in (LHV) kBtu/h	0.338	836	>51,000	
	in MW	(98 W)	0.244	>15	100 - 600
Biomass Input	in g/h	25			
	in lbs/h dry	0.055	136	>8333	
	in tons/day		1.63	>100	
	in relative size	1/2473	1	>61	407 - 2440
Biomass Input flux in g/(h cm2)		10	10	10	10
Catalyst bed diameter in cm		1.8	90	700	1805 – 4421
O2 vel. for C/O=0.7, (STP)cm/s		0.83	0.83	0.83	0.83
Air vel. for C/O=0.7, (STP)cm/s		3.12	3.12	3.12	3.12
Power density of cat.,in W/cm3		13	13	13	13
Output gas vel. in (900C)cm/s		5.6x3.76	5.6	5.6	5.6
Res. time in cat.bed(50%por), s		0.07	0.07	0.07	0.07
Raw (air)gasifier output in sft3/h			5680		
	H2+CO in ft3/h		1688		

Conclusions:

- “Desktop-size” biomass conversion demo’d by U of M (gasifiers) & PA (FT-methanol)
- A catalyst bed of 90 cm ID would process enough CLEAN biomass for10 gal/h ethanol
- Co-processing steam can widen the H2/CO from 1-1.3 to 0.9-4
- Residence time of < 70 ms is reasonable, compared to ~5 ms for a nat. gas - air flame
  ~0.1 ms for nat. gas – O2 flame

Efficient Small-Plant Biomass-to-Methanol Conversion, Rev.5



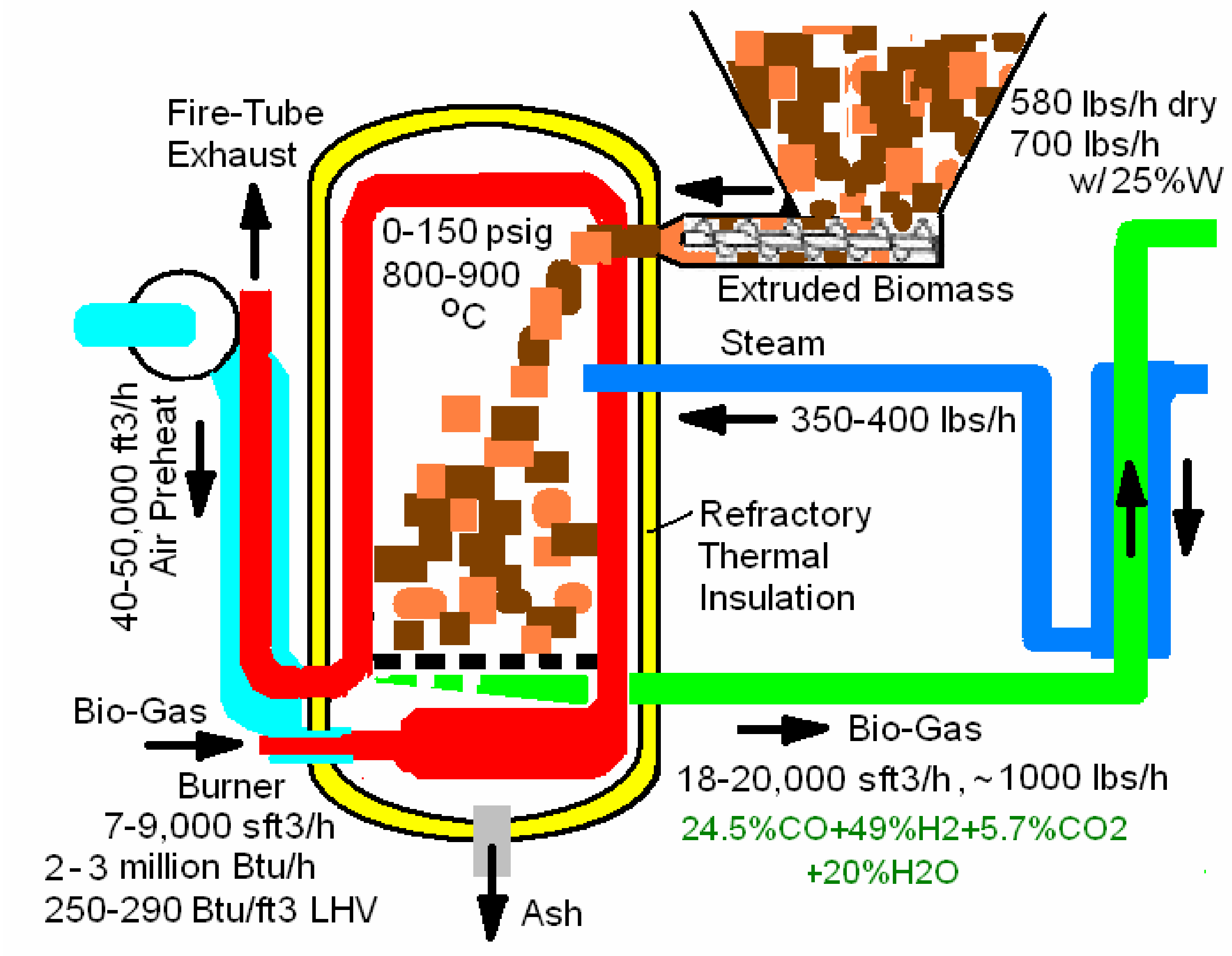
Energy in kcal/mol	13.9+ 47/.8	1.23x119.9 -17.1	32	1.91/.8/0.25 =9.6	(3.3 + 30.9)	64	32	} 339
	Heater Combustion	Gasifier	Syngas Cleanup	Compressor	FT-Reactor	Re-cycle	Product Cleanup	

$1.23\ CH_{1.64}\ N_{0.23}\ O_{0.39}\ S_{0.00035} + 0.99\ H_2O >> CH_3OH + 0.23\ CO_2 + 16.1$ kcal/mole

Conver. Eff. % = $100 * 152.8 / (1.23 * 119.9 + 47/.8 + 12.03/0.8 - 17.1 + 9.6 + 2 \times 32 + 64) = 45\ \%$

(kcal/mol) LHV Product, LHV Feedstock, Endoth. Gasificat., 50% Heater, FT Steam, Compress., Losses Product

Concept for Gasifier w/Gas-Fired Indirect Heater, Rev.7



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Composition of MinnePlant^{TM} Gasification Streams

Table 3. Flame Properties of Producer, Syngas and Methane Fuel Gases*

	Producer Gas		Prod.Flue Gas		Residual Producer Gas			Syngas		Methane	
	Equil.	**Input**	**Flame**	**Flame**	**Input**	**Flame**	**Flame**	**Input**	**Flame**	**Input**	**Flame**
P in bar	**7**	**7**	**7**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Tin in C		**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
	moles	**moles**	**mol%**	**mol%**	**moles**	**mol%**	**mol%**	**moles**	**mol%**	**moles**	**mol%**
CO	**2.39**	**2.39**	**0.41**	**1.42**	**1.39**	**1.02**	**10.44**	**1.00**	**2.01**		**0.98**
H2	**4.70**	**4.70**	**0.17**	**0.57**	**2.78**	**0.42**	**4.45**	**2.00**	**0.80**		**0.39**
CO2	**0.55**	**0.55**	**10.81**	**11.49**	**0.55**	**12.85**	**17.64**		**9.27**		**8.35**
H2O	**1.19**	**1.19**	**22.63**	**25.65**	**1.19**	**27.98**	**53.01**		**21.77**		**18.26**
O2	0.00	3.57	0.23	0.93	2.09	0.72	14.46	1.50	1.40	2.00	0.68
N2	0.00	13.65	65.75	59.94	7.97	57.01	0.00	5.74	64.75	7.65	71.34
CH4	0.00									1.00	
Tflam in C	.(844)		2075.3	2032		1944.8	2626.2		2162.2		1999.3
STANJAN	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**

* Columns Tflam = Adiabatic flame temperature TL-07-Plant-BM-sp

1: Equilibrium composition at 844°C of enough water gas for 1 mol of methanol (CH3OH)
2: Input of same composition, with air added for complete combustion at 7 bar (~ 100 psia)
3: Flame composition and temperature right after combustion with air at 7 bar
4: Same but at 1 bar; note that peak temperature is ~43°C lower than at 7 bar
5: Input same comp. as #2, except for extracting enough syngas to make 1 mole of methanol.
6: Flamed resid.prod. gas of #5 input comp. after combustion w/air at 1 bar. T4 - T6 = ~88°C
7: Flamed residual p. gas of #5 comp. after comb. w/pure O2. T7-T6 = 681°C, T7 >> T4.
8: Input extracted syngas CO+2H2. 9. After combustion w/air. T9 - T4 = 130°C, T9-T6= 217 °C
10: Input methane + air. 11: Flamed methane after combustion with air. T4 > T11 > T4

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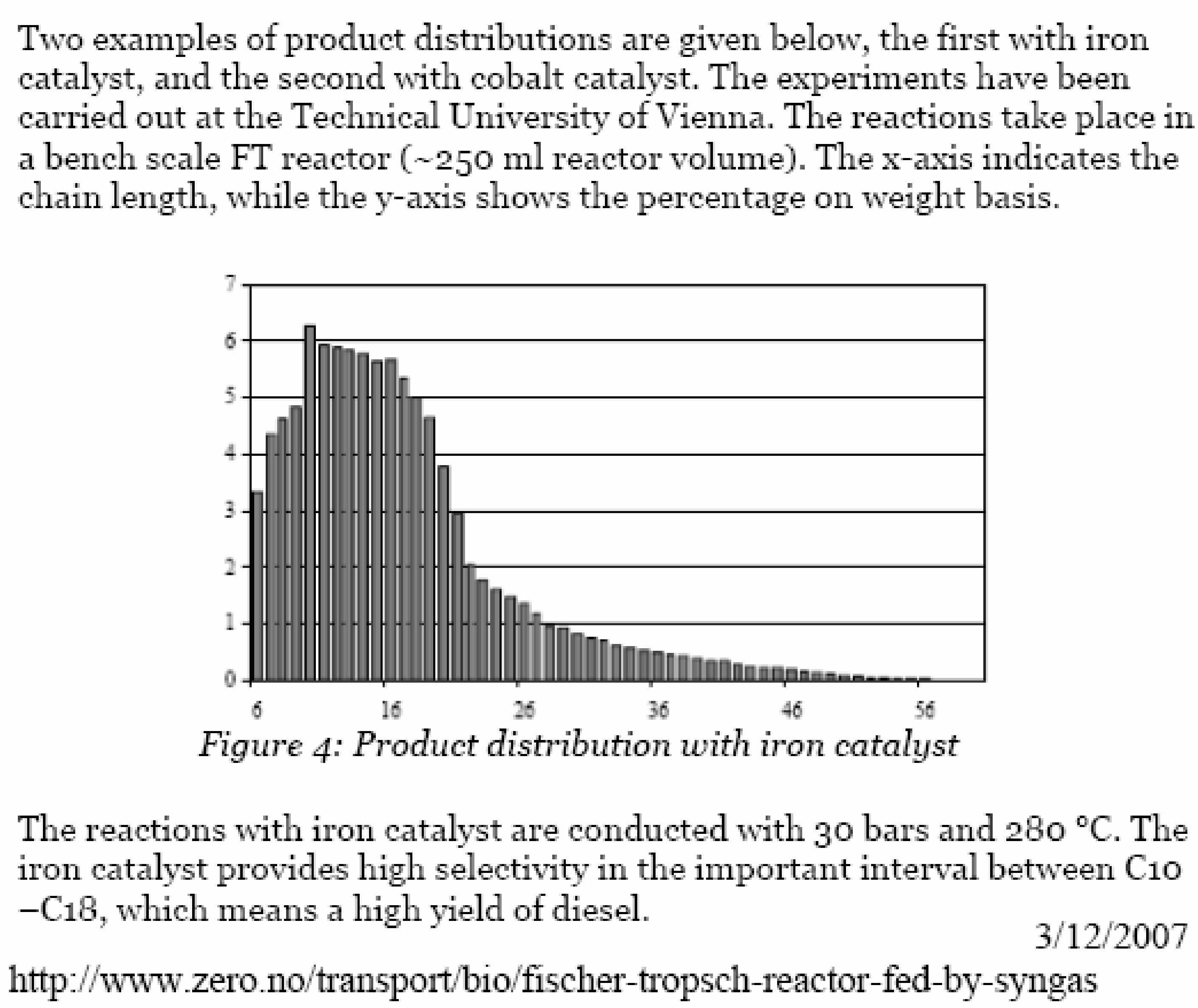
Developmental Equipment: FT-Catalytic Converter



Two examples of product distributions are given below, the first with iron catalyst, and the second with cobalt catalyst. The experiments have been carried out at the Technical University of Vienna. The reactions take place in a bench scale FT reactor (~250 ml reactor volume). The x-axis indicates the chain length, while the y-axis shows the percentage on weight basis.

Figure 4: Product distribution with iron catalyst

The reactions with iron catalyst are conducted with 30 bars and 280 °C. The iron catalyst provides high selectivity in the important interval between C10 –C18, which means a high yield of diesel.

3/12/2007

http://www.zero.no/transport/bio/fischer-tropsch-reactor-fed-by-syngas

Composition of Conceptual FT-Output Streams

Table 4. Equilibrium FT product gas yield sensitivity to pressure, xi and source gas

	----------------------------Source Gas: Pure Syngas of H2/CO=2, Pressure in bar--------------------------------								
250C	**1**	**10**	**100**	**100**	**10**	**1**	**1**	**10**	**100**
CO	0.054	0.009	0.002	17.718	32.38	33.323	0.054	0.009	0.002
H2	20.630	6.630	1.779	35.436	64.76	66.646	20.630	6.629	1.778
CO2	12.127	8.424	7.132	0.000126	0.000069	0.000	12.129	8.428	7.140
H2O	51.331	66.275	71.466	0.000003	0.000002	0.000	51.325	66.261	71.436
CH3OH	0.048	0.086	0.130 ppm	46.84 in%	2.8595	0.031			
C4H10	15.846	18.634	19.564	single products			15.863	18.672	19.644
C6H14	0.012	0.028	0.057						
C3H8					21.551				
CO				1.795	6.330	6.713	0.064	0.013	0.003
H2				54.774	66.611	67.119	18.288	5.445	1.402
CO2				24.010	23.715	23.563	17.870	15.053	14.162
H2O				8.081	2.753	2.599	55.954	69.848	74.220
CH3OH		single products		11.340	0.591	0.006			
C4H10		single products					7.823	9.642	10.213
				--------------------Source Gas: Producer Gas--------------------------------					

* All calculations are for 250C and H2/CO=2, equil.compos.   TL-07-Plant-BM-sp, U.Bonne, 21 Feb.'08

Conversion yield to CH3OH (methanol) is strongly pressure-dependent, or about >20x /decade
The pressure-dependence of the yield for hydrocarbons is much weaker, e.g. for C4H10 (butane)
The presence of CO2 and H2O (direct use of producer gas) reduces the yields of C4H10 by 2x
Catalysis to both CH3OH and C4H10 reduces the yield of the former by ~106x
The pressure-dependent yields for CH3OH and C4H10 cross over between 10 and 100 bar
The above scenario may well change as temperature, H2/CO ratio and product mix change.

Product Yield of Conceptual FT Output Streams

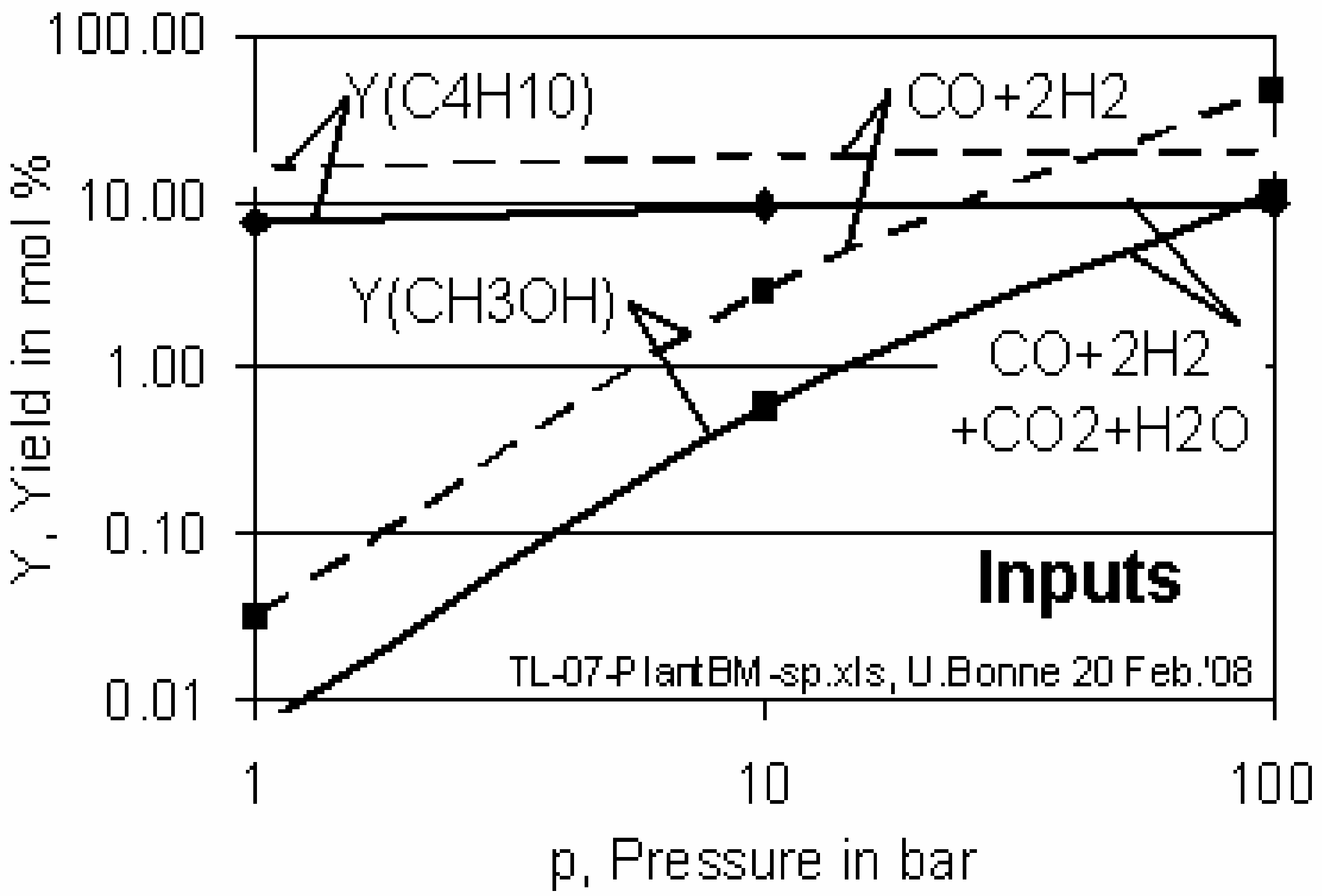


Fig. 3. Best product yield versus pressure

Efficient Small-Plant Biomass-to-Methanol Conversion

SENSITIVITY ANALYSIS

Different BM Mat’l: xBM + yH2O >> CH3OH + (x-1)CO2 + 16.06 kcal/mol

BM Materials	x mol	y mol	Eff %	ΔHgas	ΔHFT	ΔHtot	ΔHf	Materials
					kcal/mol			
CH 1.67 O.833	1.50	.75	**46.51**	35.27	-30.9	4.38	-38.5	cellulose
CH 2.00 O 1.0	1.50	.5	**47.4**	35.00	-30.9	4.10	-49.68	glucose
CH 1.90 O.178	1.08	.97	**42.33**	87.74	-30.9	56.84	-51.75	lignin
CH 1.64 O .39	1.23	.99	**45.28**	46.96	-30.9	16.06	-22.66	BM=biomass(NREL)
CH 1.64 O .39	1.23	.99	**45.32**	46.96	-30.9	16.06	-22.66	BM 820C Tgas
CH 1.64 O .39	1.23	.99	**45.09**	46.96	-30.9	16.06	-22.66	BM 200C FT
CH 1.64 O .39	1.23	.99	**46.24**	46.96	-30.9	16.06	-22.66	BM HXgf=60%
CH 1.64 O .39	1.23	.99	**46.46**	46.96	-30.9	16.06	-22.66	BM HXFT=60%
CH 1.64 O .39	1.23	.99	**48.14**	46.96	-30.9	16.06	-22.66	BM HXcb=90%
CH 1.64 O .39	1.23	.99	**46.25**	46.96	-30.9	16.06	-22.66	BM pFT=500psia
CH 2.01 O .39	1.15	.85	**44.88**	57.60	-30.9	26.70	-35.20	BM w/ H=2.01
CH 1.64 O .83	1.51	.76	**48.66**	11.37	-30.9	-19.53	-22.66	BM w/ O=0.83

Reference Op. Conditions: Tgasfier = 920°C; TFT = 250°C
pFT = 600 psia (~40 bar)
HXcb = 80%; HXgf = 50%; HXFT = 50%
BM (NREL) Material: $CH_{1.64}O_{0.39}N_{0.23}S_{0.0035}$

Efficient Small-Plant Biomass-to-Methanol Conversion

CONCLUSIONS

- Each 1 Btu of produced methanol consumes 2.2 Btu of biomass feedstock, of which 0.96 Btu is converted to methanol, with the addition of 0.03 g of recycled water

- Each 1 gal of produced methanol consumes 13.5 lbs of biomass feedstock, of which 5.8 lbs are converted to methanol, with the addition of 0.4 gal of water, which is obtained from recovered condensates. This amounts to 148 gal methanol / ton of biomass.

- Such plant yield is 1.65x higher than the traditional corn-ethanol yield of 90 gal/ton (disregarding HV differences between these fuels for the moment), and would yield 3.3x more fuel/acre if both corn and stover were processed to fuel.

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Where do we go from here?

- Select gasification and GTL conversion system
- Identify development partners, as needed
- Leverage MN renewable resources and labor pool
- Prepare comprehensive business plan
- Iterate technical and economic models, scale up and cost-engineer “small plant”
- Verify performance of scaled up small plant
- Launch manufacture of “universal” small plants to minimize use of fossil, non-renewable fuels

Collaboration and Innovation

"IBM is re-inventing the way it innovates. At one time the tech giant was a true believer on go-it-alone R&D. The feeling was that if a technology wasn't invented by IBMers, it wasn't as good. Now the computer pioneer realizes that no matter how big an organization is, more smart people are going to work outside its walls than inside. So it courts R&D partners aggressively. **'We are the most innovative when we collaborate,'** declares Chief Executive Samuel J.Palmisano".

THANK YOU !
ANY QUESTIONS?

p.18 of the Innovation Insert of
Business Week issue of Sept.10, 2007

Biomass vs. Solar PV Energy Yield & Investm.

	$inv/acre	**$inv/kW**	**W/acre**	**$earn/y/acre**	**$earn/y/$inv**
Biomass Plant + ag.cultiva	500	11,855	2,153	1,100	2.200
Biomass Plant -- 200 acres	1,250	29,639	1,054	685	0.548
BioMax25 Gasifier+Generator		8,000			
Solar PV Cell			82,175	50,390	0.101
Solar PV Cell - GE in Portu	500,000	6,818	73,333	44,968	0.090
Ratio BioMass/PV Cell	~0.001	~2	**~1/70**	~1/27	**~24/1**

Biomass kWh earnings per acre may be 70x lower than PV, but return on $- inv is 24x higher

PV earnings per invested $ may be 24x lower, but should require less labor after installation

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Developmental Equipment: Corn+Stover Harvester

Iowa State Developing Integrated Corn and Stover Harvester. A dual-stream, single-pass harvesting system to harvest corn and corn stover in two separate streams is being developed by Stuart Birrell et al, at Iowa State U (sbirrell@iastate.edu) sponsored by USDA-DOE and John Deere Co.. 31 Dec. 2006, see http://www.iastate.edu/~nscentral/news/06/dec/stover.shtml and http://thefraserdomain.typepad.com/energy/2006/12/iowa_state_deve.html#comment-72586652
Left: The Integrated Harvester chops stover into 2”-pieces, and the blower throws the chopped stover into a wagon. Dual harvesting speed is equal to a normal grain harvest when less than 50 % of the stover is collected, as shown at **far right**. When all of a field's stover is collected (see middle of right photo) harvest speeds are about half, but the goal is to get the speed to at least 80 % of a normal grain harvest, no matter how much stover is collected. Stover would be easier to transport and to store if its density could be increased from the normal range of 0.048 to 0.064 g/cm3 (3-4 lbs/ft3) to a range of 0.16 to 0.19 g/cm3 (10-12 lb/ft3).

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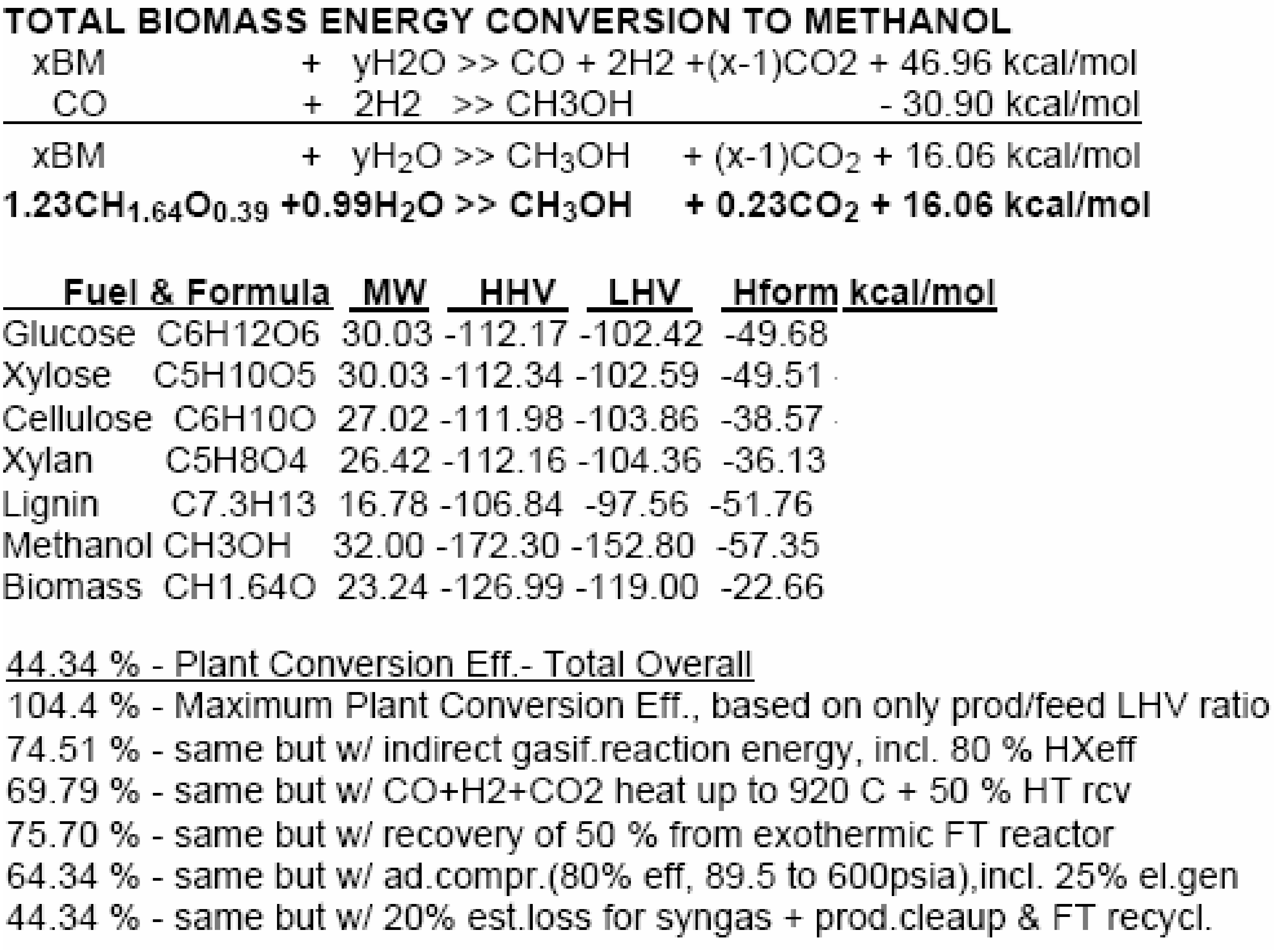
Small Biomass Plant Energy Conversion Efficiencies-3



TOTAL BIOMASS ENERGY CONVERSION TO METHANOL

$x\mathrm{BM} + y\mathrm{H_2O} \gg \mathrm{CO} + 2\mathrm{H_2} + (x-1)\mathrm{CO_2} + 46.96\ \mathrm{kcal/mol}$

$\mathrm{CO} + 2\mathrm{H_2} \gg \mathrm{CH_3OH} - 30.90\ \mathrm{kcal/mol}$

$x\mathrm{BM} + y\mathrm{H_2O} \gg \mathrm{CH_3OH} + (x-1)\mathrm{CO_2} + 16.06\ \mathrm{kcal/mol}$

$\mathbf{1.23CH_{1.64}O_{0.39} + 0.99H_2O \gg CH_3OH + 0.23CO_2 + 16.06\ kcal/mol}$

Fuel & Formula		MW	HHV	LHV	Hform kcal/mol
Glucose	$C_6H_{12}O_6$	30.03	-112.17	-102.42	-49.68
Xylose	$C_5H_{10}O_5$	30.03	-112.34	-102.59	-49.51
Cellulose	$C_6H_{10}O$	27.02	-111.98	-103.86	-38.57
Xylan	$C_5H_8O_4$	26.42	-112.16	-104.36	-36.13
Lignin	$C_{7.3}H_{13}$	16.78	-106.84	-97.56	-51.76
Methanol	CH_3OH	32.00	-172.30	-152.80	-57.35
Biomass	$CH_{1.64}O$	23.24	-126.99	-119.00	-22.66

44.34 % - Plant Conversion Eff.- Total Overall

104.4 % - Maximum Plant Conversion Eff., based on only prod/feed LHV ratio

74.51 % - same but w/ indirect gasif.reaction energy, incl. 80 % HXeff

69.79 % - same but w/ CO+H2+CO2 heat up to 920 C + 50 % HT rcv

75.70 % - same but w/ recovery of 50 % from exothermic FT reactor

64.34 % - same but w/ ad.compr.(80% eff, 89.5 to 600psia),incl. 25% el.gen

44.34 % - same but w/ 20% est.loss for syngas + prod.cleaup & FT recycl.