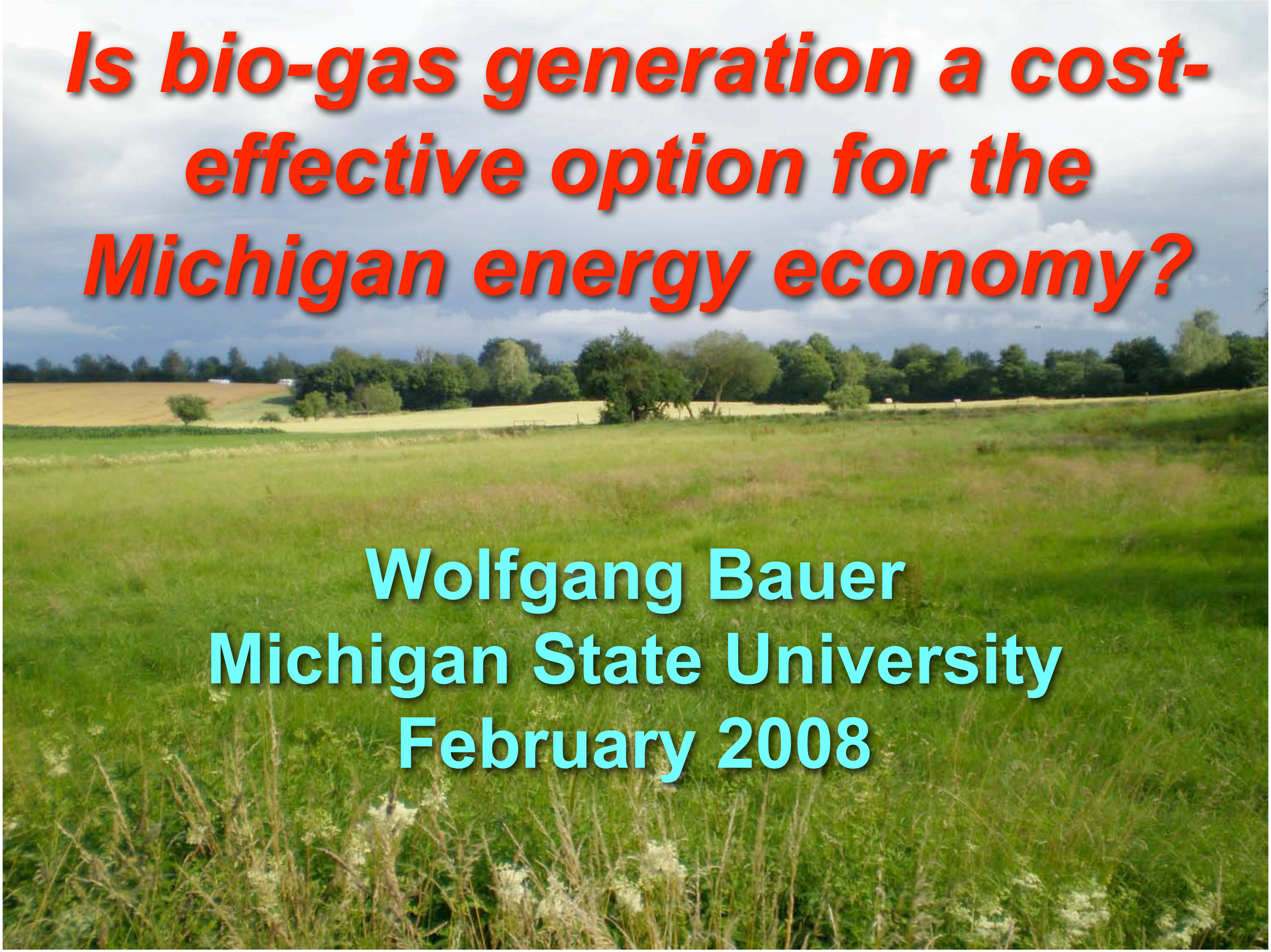
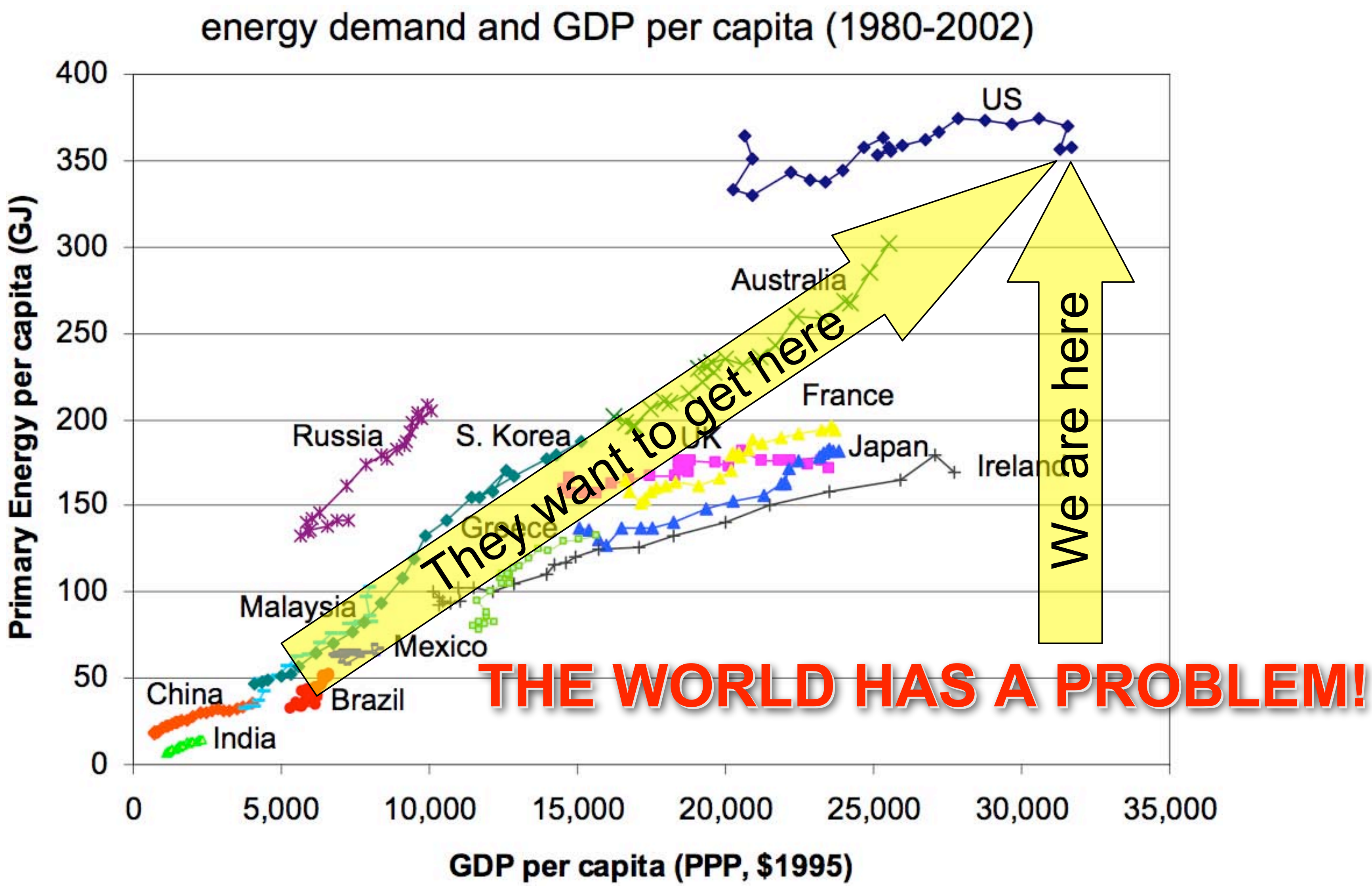

Is bio-gas generation a cost-effective option for the Michigan energy economy?
Wolfgang Bauer
Michigan State University
February 2008

Energy Use = Wealth

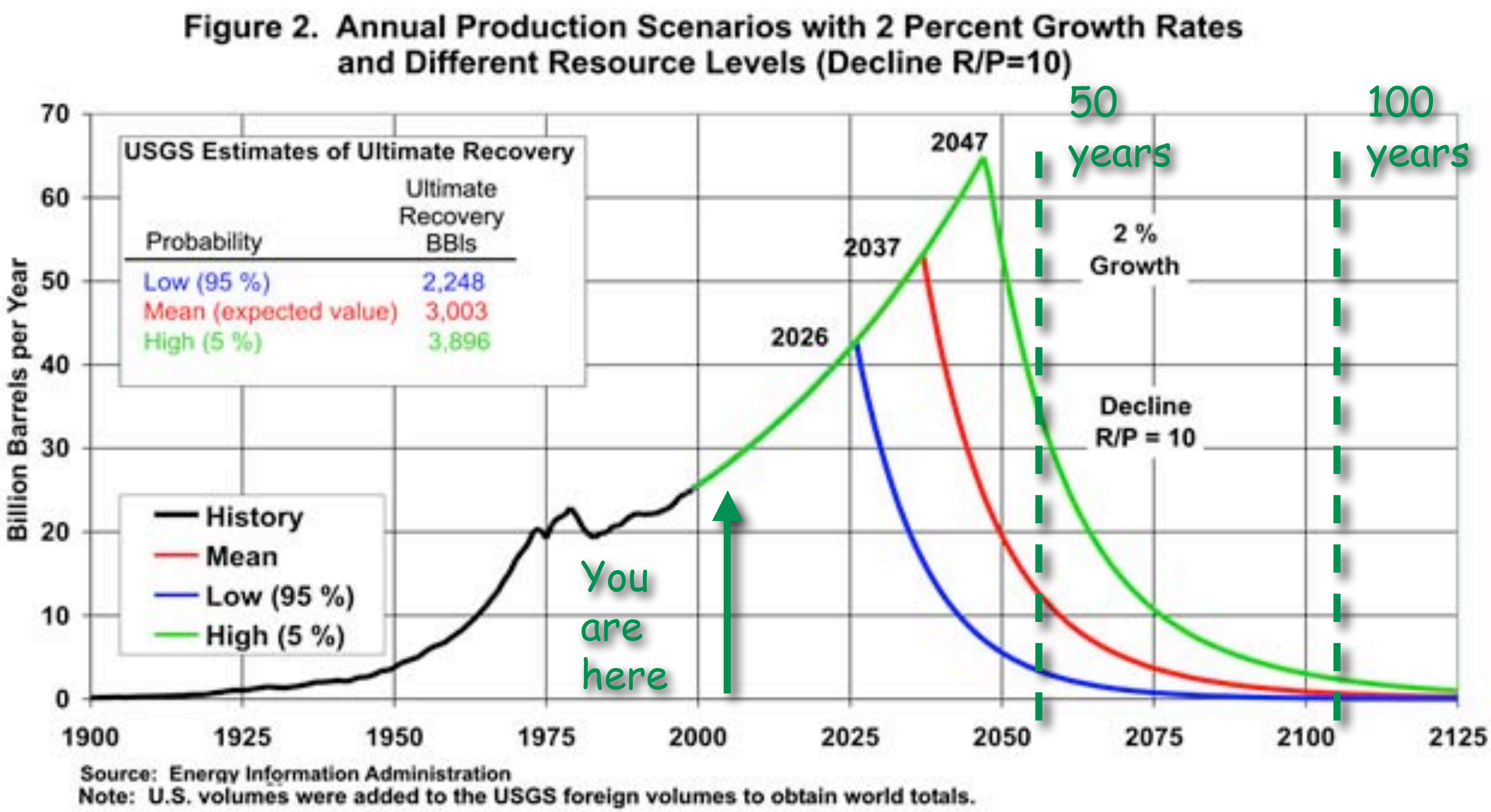


Source: UN and DOE EIA

How much is 350 GJ/year?

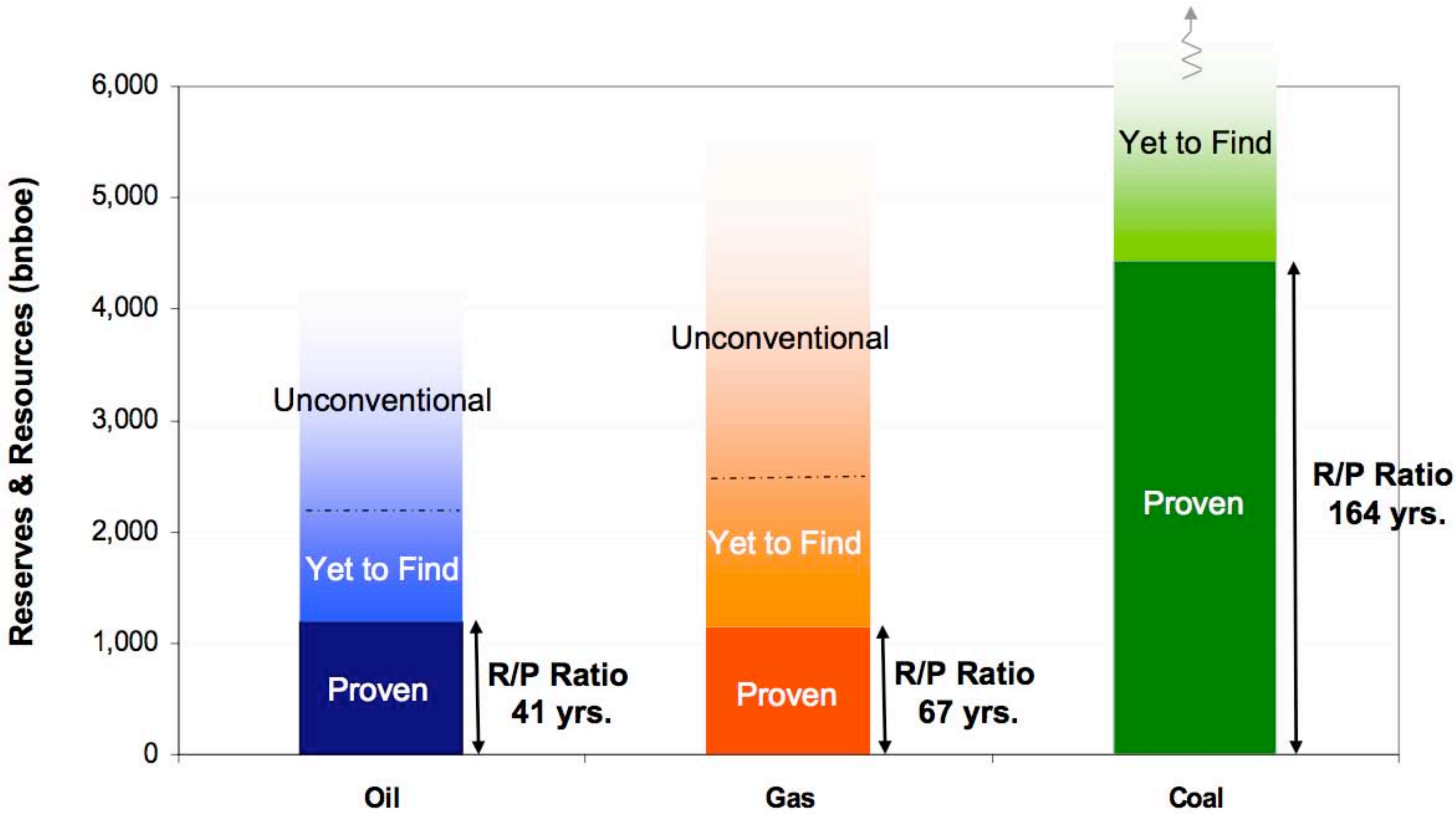
- We eat about 2,500 Cal/day (~10 MJ/day)
- Food consumption/year: ~3.5 GJ
- 350 GJ = food consumption of 100 people
- "is the equivalent of having ~ 100 energy 'servants'" (Steve Chu)

We are running out of oil!



http://www.eia.doe.gov/

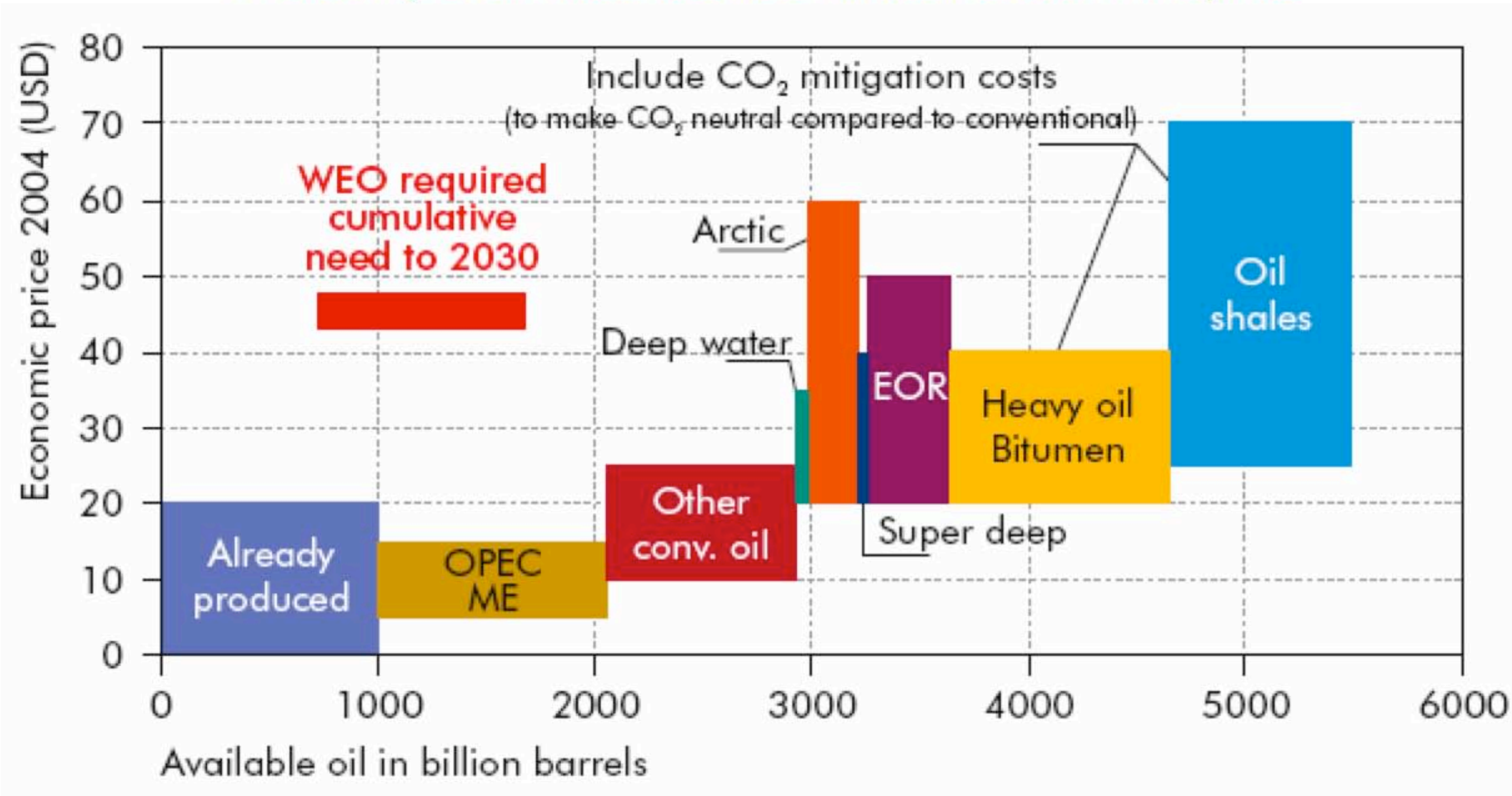
… but not coal (for a while)



Source: World Energy Assessment 2001, HIS, WoodMackenzie, BP Stat Review 2005, BP estimates

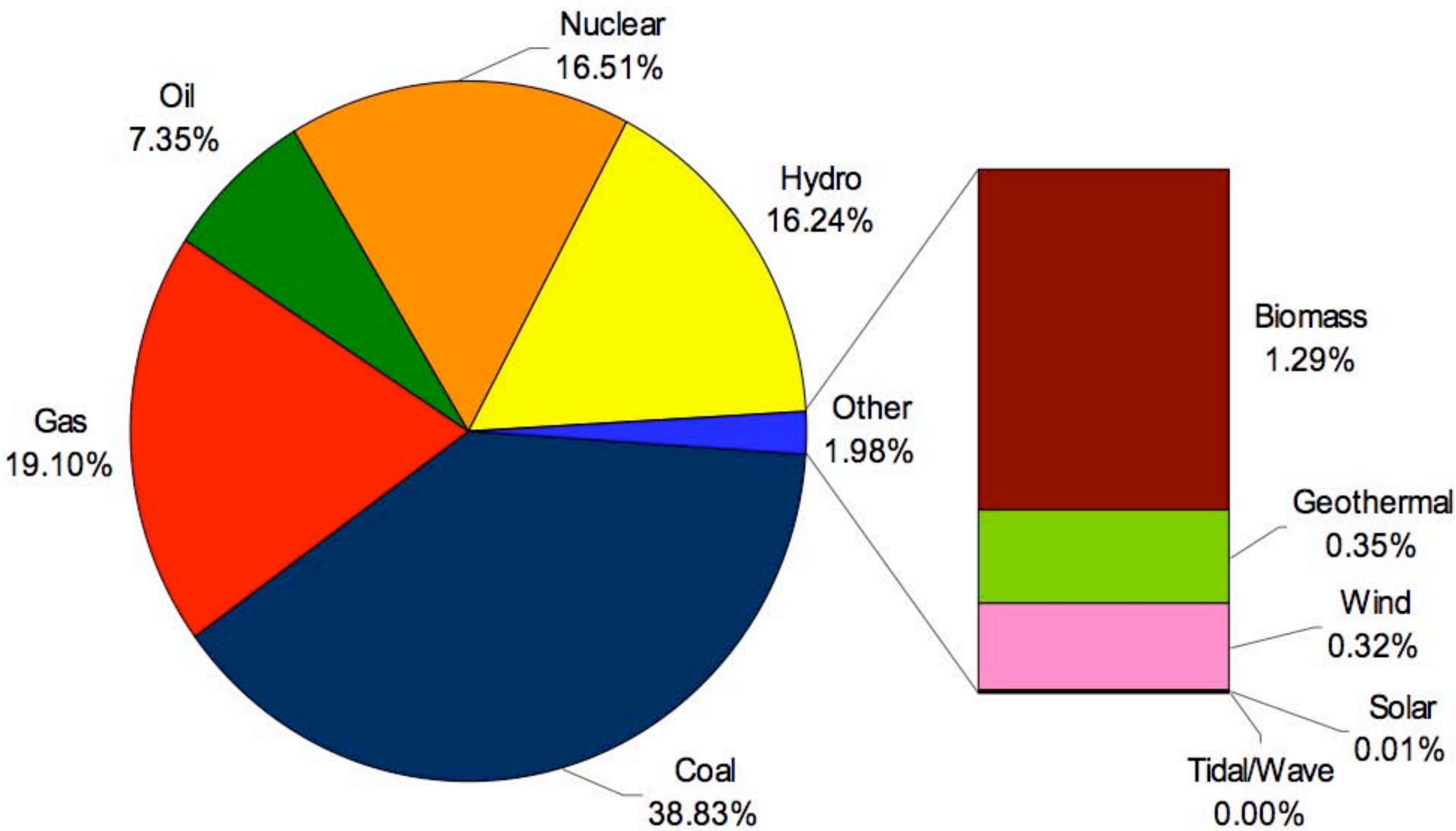
Hidden oil … at a price

Availability of oil resources as a function of economic price



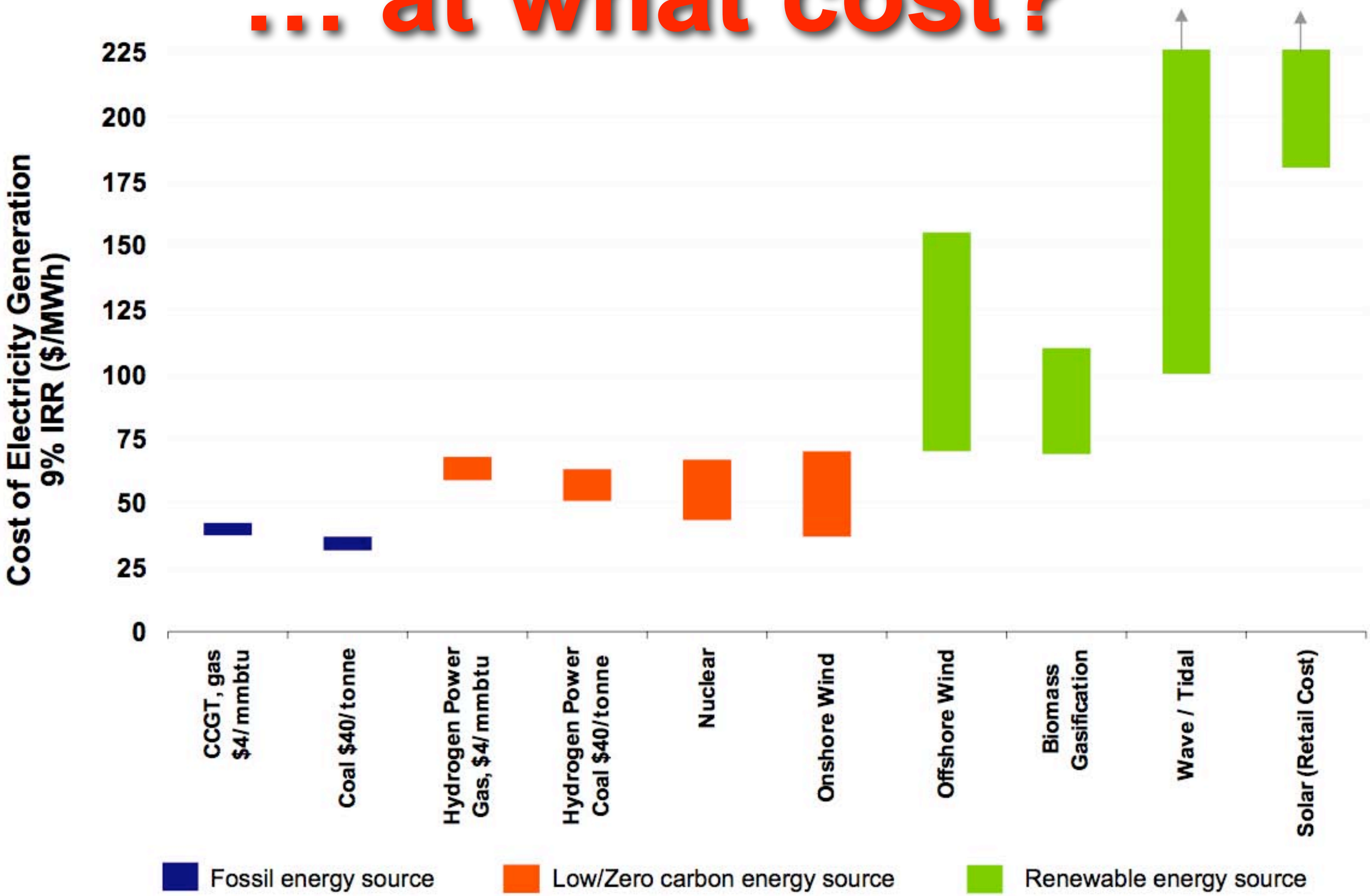
Source: IEA (2005)

US Electricity Generation



Source: IEA WEO

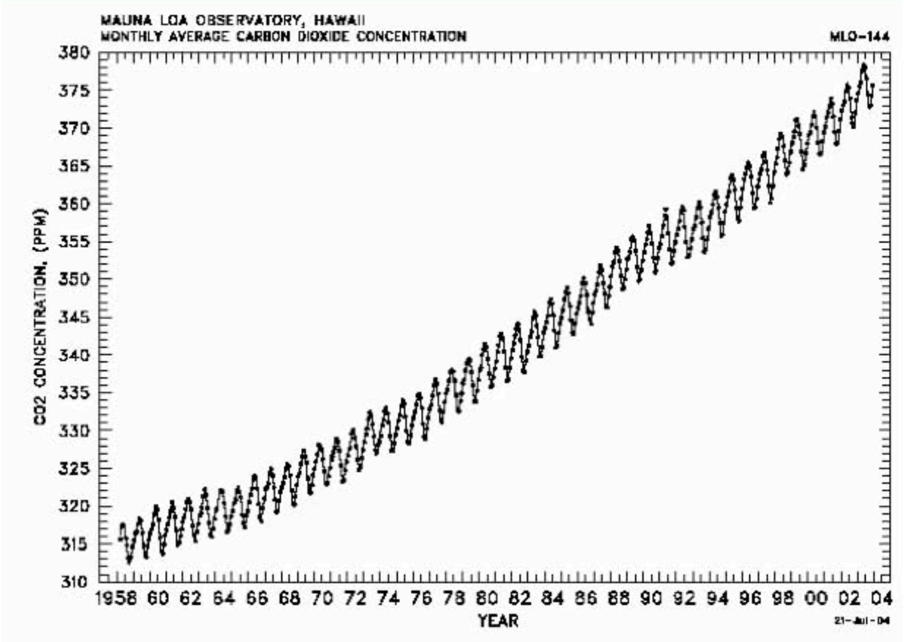
… at what cost?

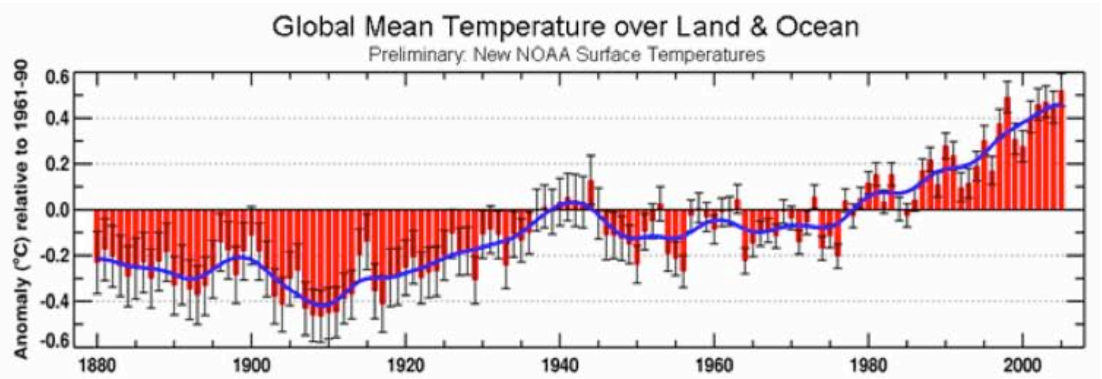


Source: BP Estimates, Navigant Consulting

CO_2 increase correlated with global temperature rise!

- CO_2 concentration is rising due to fossil fuel use
- The global temperature is increasing
  - other indicators of climate change
- There is a plausible causal connection
  - but the scientific case is complicated by natural variability, ill-understood forcings
- Impacts of higher CO_2 quite uncertain
  - ~ 2X pre-industrial is a widely discussed stabilization target (550 ppm)
  - Reached by 2050 under BAU
- Precautionary action is warranted
  - What could the world do?
  - Will we do it?

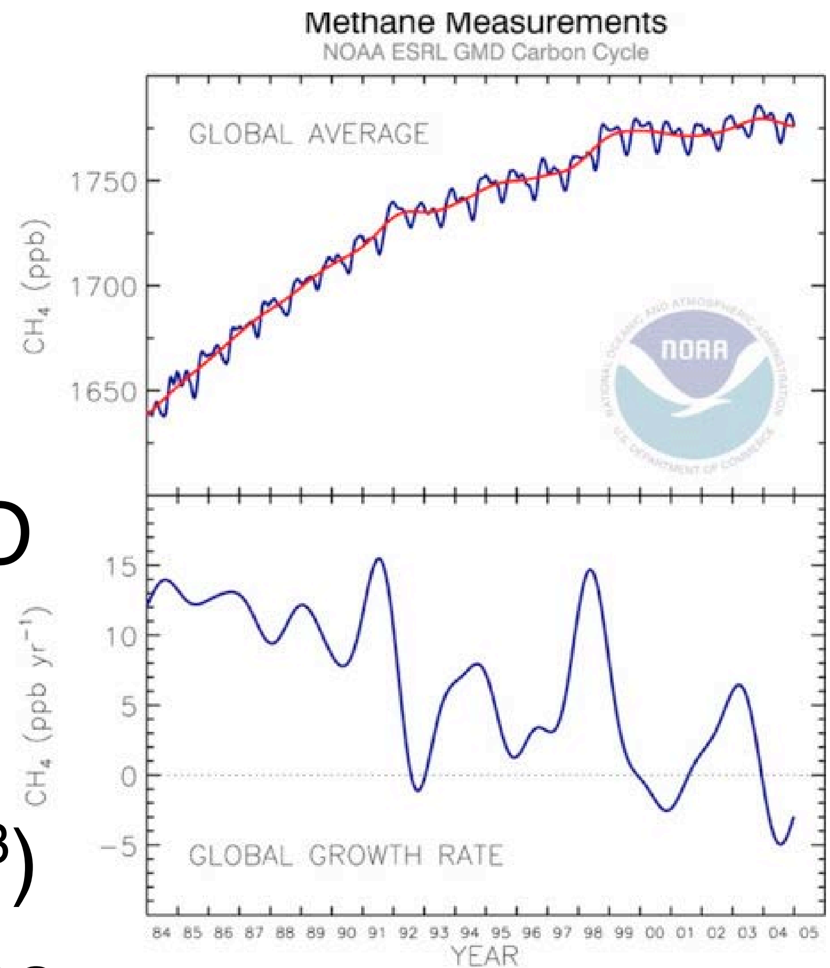




… while we are at it:
Steve Koonin will get an honorary degree from MSU on May 2nd, and will give the Physics and Society lecture on May 1st, at 8 pm in the Kellogg Center Auditorium

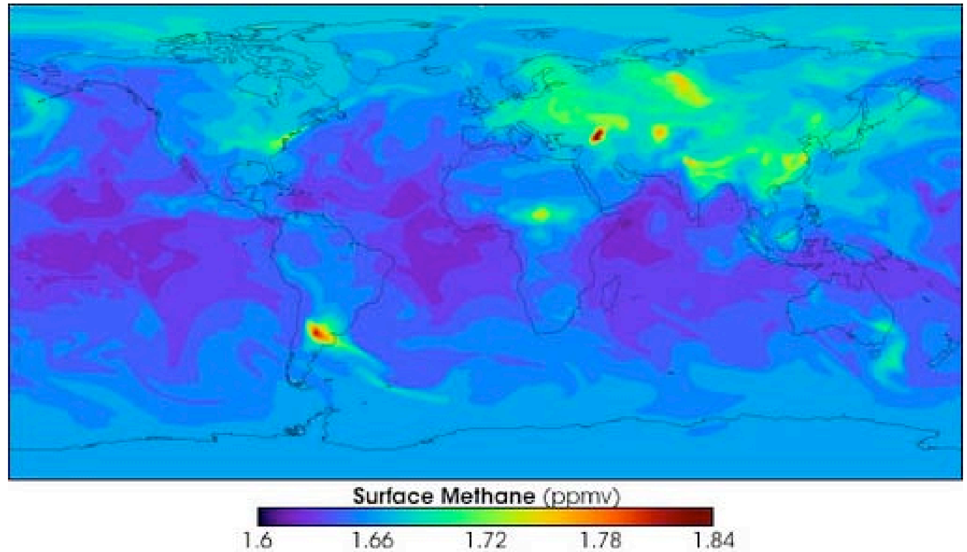
Methane

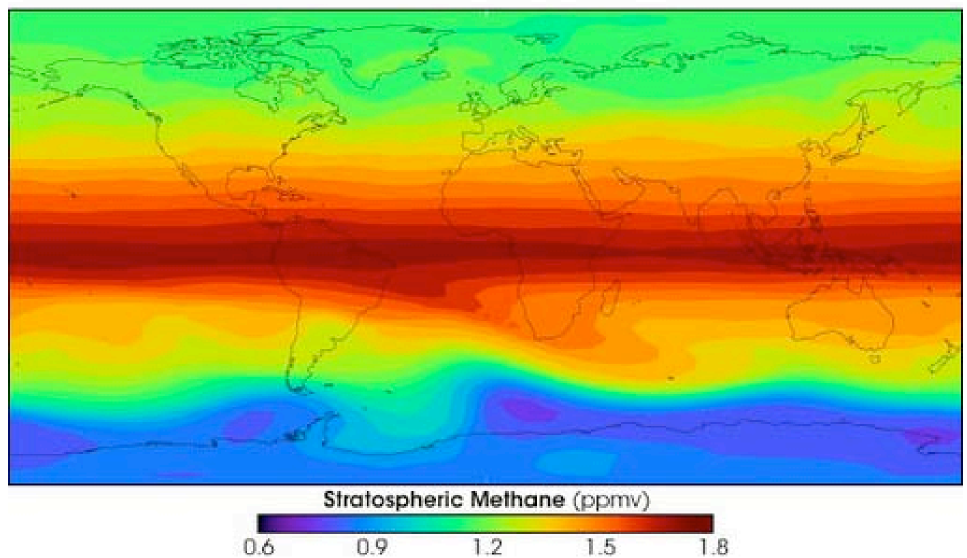
- Hydrocarbon fuel, CH_4
- "Natural" gas
- Most important reaction
  $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
- Heat of combustion:
  802 kJ/mol
  (~1000 BTU/ft^3, ~1 MJ/ft^3)
- Important greenhouse gas



Origin	CH_4 Emission		
	Mass (Tg/a)	Type (%/a)	Total (%/a)
Natural Emissions			
Wetlands (incl. Rice agriculture)	225	83	37
Termites	20	7	3
Ocean	15	6	3
Hydrates	10	4	2
Natural Total	270	100	45
Anthropogenic Emissions			
Energy	110	33	18
Landfills	40	12	7
Ruminants (Livestock)	115	35	19
Waste treatment	25	8	4
Biomass burning	40	12	7
Anthropogenic Total	330	100	55
Sinks			
Soils	-30	-5	-5
Tropospheric OH	-510	-88	-85
Stratospheric loss	-40	-7	-7
Sink Total	-580	-100	-97
Emissions + Sinks			
Imbalance (trend)	+20	~2.78 Tg/ppb	+7.19 ppb/a

Houweling et al. *Climate Change 2001*





http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=16827

Bio-Ethanol: not worth it

- Ethanol production receives > $3 billion/year in subsidy in US
- Goal: become independent of fossil fuels
- But: corn ethanol production requires 29% more fossil energy input than the energy output in the fuel produced (switch-grass 45%, wood 57%)
- Bio-diesel from soybeans or sunflowers (27%, 118%)

David Pimentel & Tad Patzek,
Natural Resources Research (Vol. 14:1, 65-76)

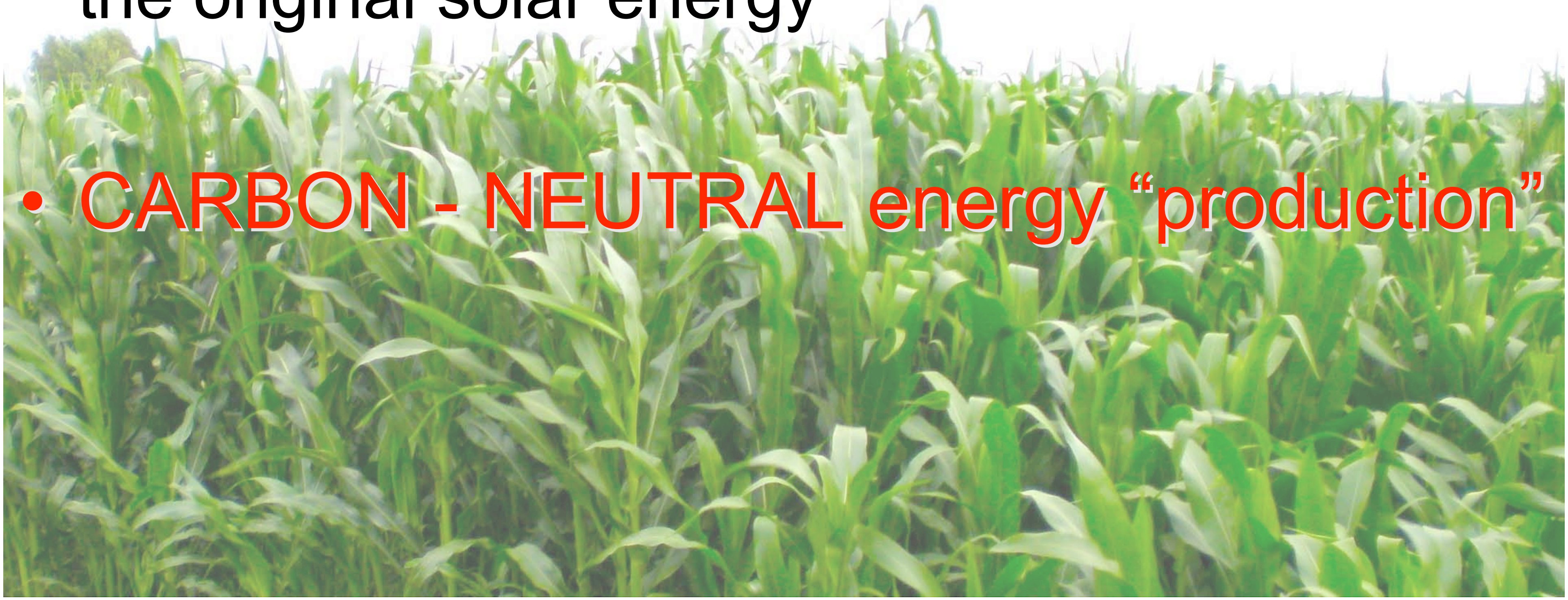
Bio-Ethanol

- Future: perhaps cellulosic ethanol
- MSU expert: Bruce Dale
- Nature's expert: microbes in termite gut (break down wood cellulose into "fuel")
- Commercial interest: Iogen, SunOpta (Steam Explosion pre-treatment)

Biogas Power Plant

Basic Operation

- Plants convert solar radiation, ground water, and atmospheric CO_2 into biomass
- Fermenting the shredded plants releases methane, which is burned to liberate some of the original solar energy



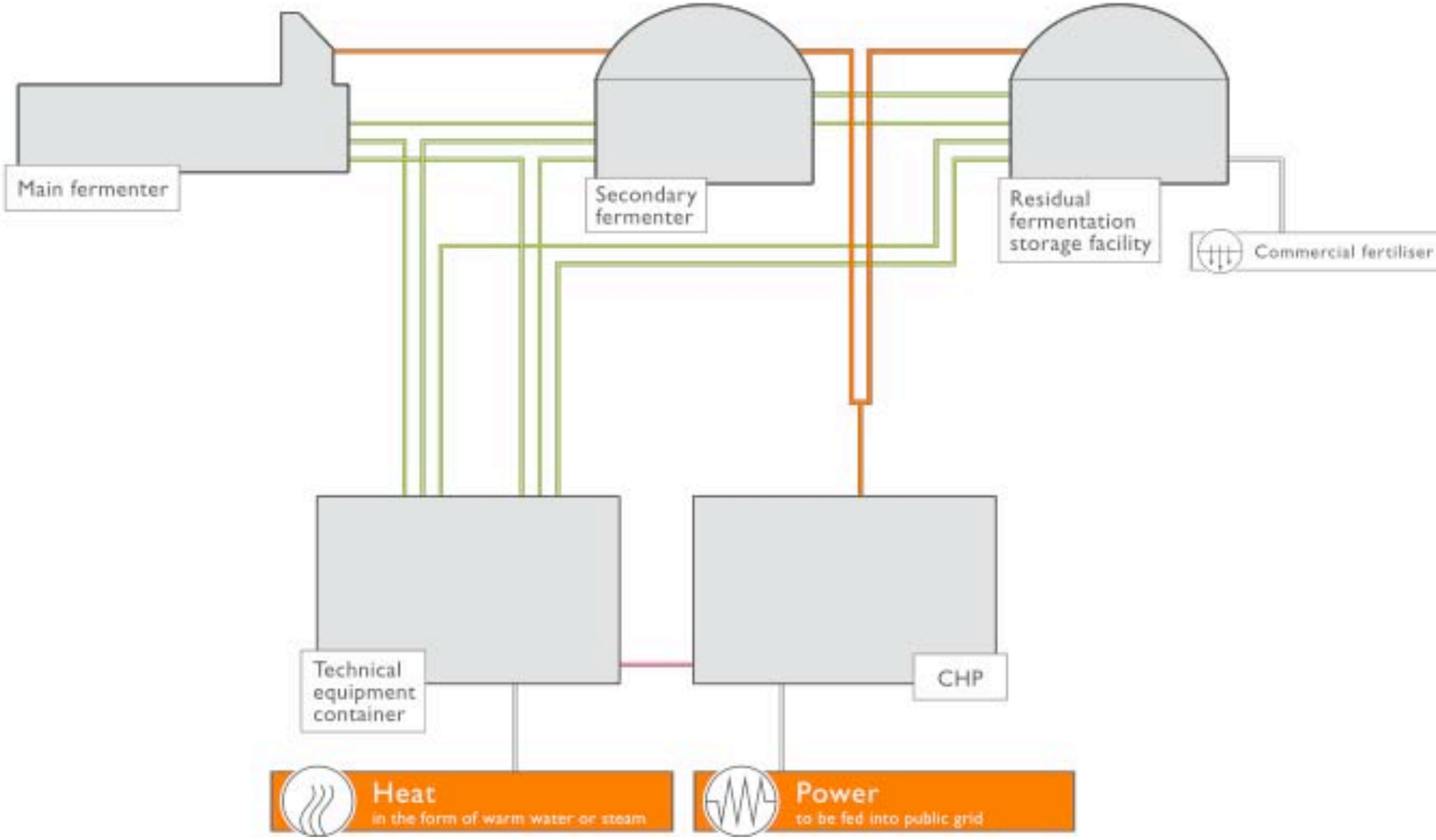
- CARBON - NEUTRAL energy “production”

Raw material: Corn (whole plant)

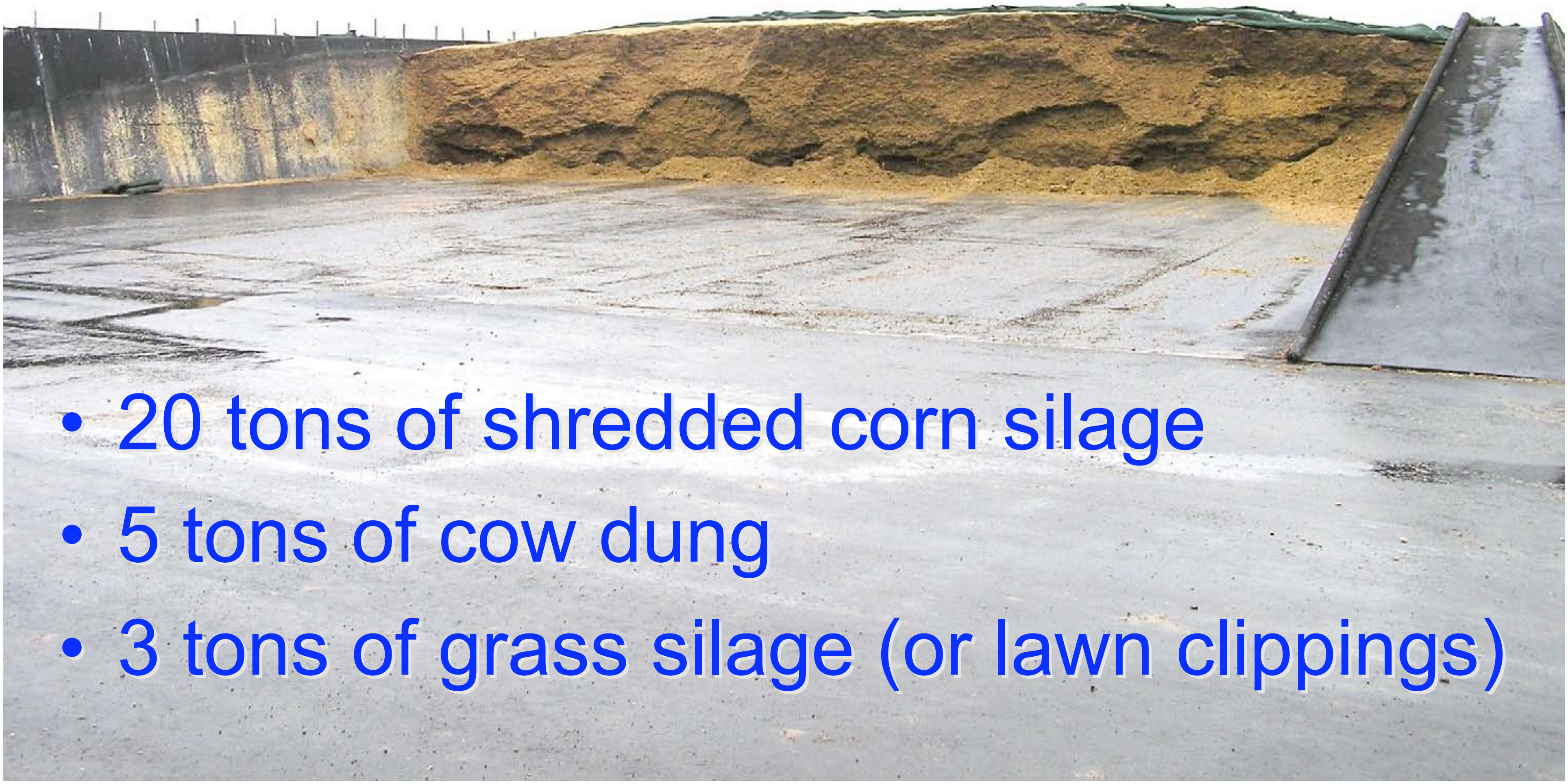
Power Plant Layout

COWATEC

Biogas plant flowchart



Biomass Consumption / Day



- 20 tons of shredded corn silage
- 5 tons of cow dung
- 3 tons of grass silage (or lawn clippings)

Mixer


VMix
Bio
BvL
van Lengerich

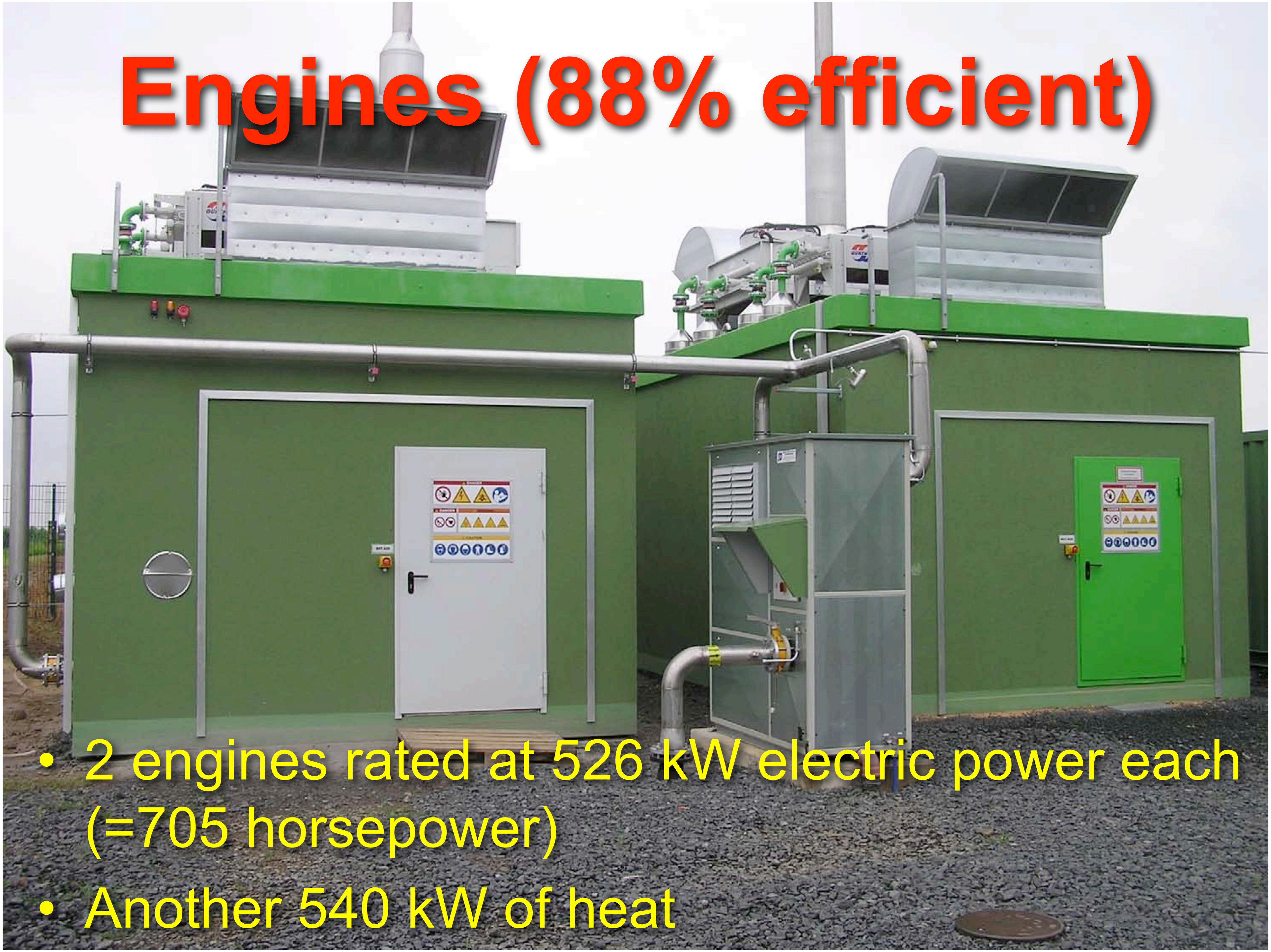
Fermenter

- Annual residue production:
  - 10,000 cubic yards of solid/liquid mixture
  - High quality (non-smelly!!!) fertilizer

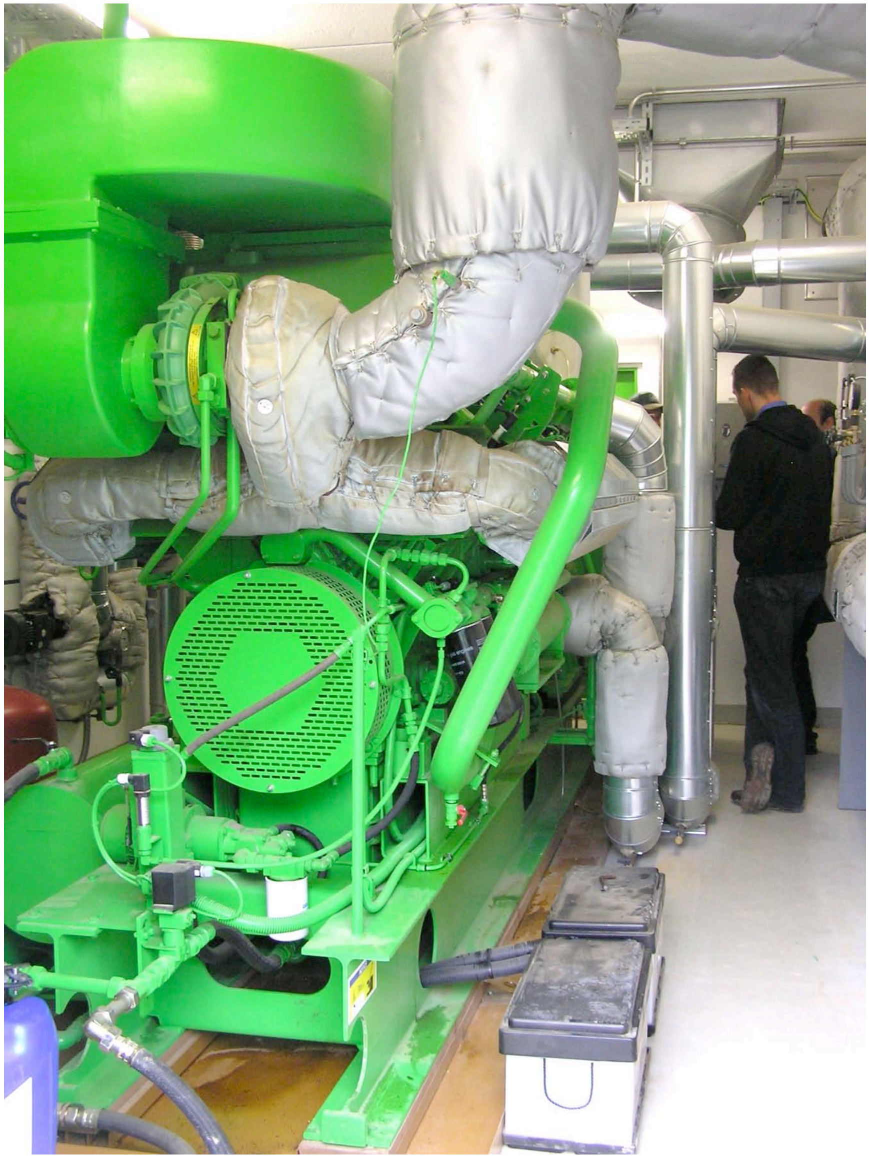
Gas Storage

- 9,000 cubic yards of gas/day
- 50% methane
- Equivalent energy content of 4,500 cubic yards of natural gas

Engines (88% efficient)



- 2 engines rated at 526 kW electric power each (=705 horsepower)
- Another 540 kW of heat



Bottom Line

- Initial investment: ~ $3-5 million
- Land required to grow biomass: 150 hectares (= 370 acres)
- 4.6 million kWh of electrical energy/year
- 5 million kWh of thermal energy
- Go GREEN!

Figure of Merit

- 1.2 kW/m^2 of solar radiation
- Real value for Michigan: ~100 W/m^2 ($\cos\theta$, day/night, clouds, …).
- 150 hectares = $1.5 \cdot 10^6$ m^2
- Maximum possible power capture: ~$1.5 \cdot 10^8$ W
- Present efficiency = 0.5 MW / 0.15 GW = 0.3%
- Room for improvement!

Biogas plant optimisation approaches

Biogas plant

Energy crops
- Recommendations concerning cultivation and plant varieties
- Harvesting and transport
- Storage
- Reduction of silage losses

Fermentation residue recycling
- Quantity forecast
- Fermentation residue analyses of N, P and K content
- Dry solid matter quantity
- Fertilisation recommendation

Performance values
- Electrical energy generation
- Thermal energy generation
- Process energy consumption
- Power and heat utilisation

Process engineering design
- Residence time
- Space load
- Space/time yield

Gas quality
- Methane, carbon dioxide, hydrogen oxygen, hydrogen sulphide
- Moisture

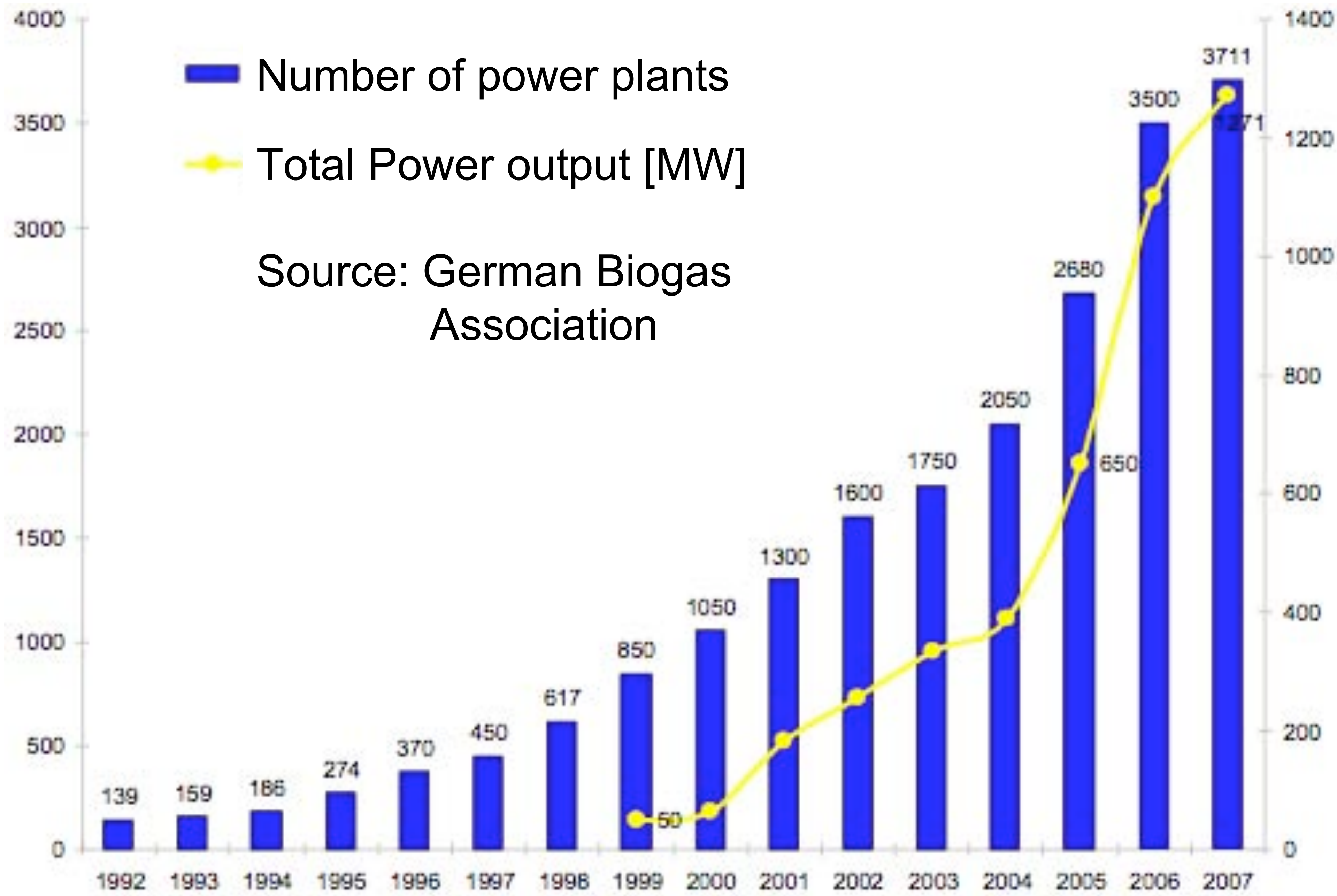
Feeding management
- Input quantity (fresh biomass)
- Theoretical gas yield
- Feed quality
- Charging intervals
- Quantity of recirculate
- Inhibitors
- Operating resources (e.g. MethaPlus)

Fermentation process
- Fatty acid analysis
- Evaluation of operating data
- pH
- Redox potential
- Volatile organic acids TAC (alkaline buffer capacity), carbon/nitrogen ratio
- NH_4 content
- Temperature
- Maintenance and calibration

Cowatec AG takes a holistic approach to the provision of services, ranging from the optimisation of biomass (e.g. energy crop cultivation) and biological processes to reducing the plant's susceptibility to breakdowns. Energy and profit losses are thus substantially reduced.

Biomass in Germany

- 2006: 17 billion kWh from biomass (10 from wood, 5 from biogas, 1 from plant oils)
- 2007: 3700 biogas plants with 1.3 GW total power
- Projection for 2020: 76 billion kWh (2% of all energy consumption in Germany)



Number of power plants
Total Power output [MW]
Source: German Biogas Association
4000
3500
3000
2500
2000
1500
1000
500
0
1400
1200
1000
800
600
400
200
0
139
159
186
274
370
450
617
850
1050
1300
1600
1750
2050
2680
3500
3711
50
650
1271
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007

Area Comparison

Germany:	350,000 km^2;	82 million people
Michigan:	147,000 km^2;	10 million people

Research Opportunities

- What are the best plants to capture solar energy most rapidly?
  - Optimize total biomass production per day
  - Multiple harvests per year
  - Candidates: corn, switch-grass, small poplars, (genetically engineered plants?)
  - **Plant Science research projects**

Research Opportunities

- What are the best bacteria to convert plant material into methane?
  - Presently: random bacteria collection from cow dung + some enzymes
  - Can one create a better and more efficient microbial cocktail for fermentation?
  - **Microbiology research projects**

Research Opportunities

- Can one transport the methane gas to end-users in a cost-effective way?
  - Present: burn methane locally
  - Alternative: transport methane through natural gas pipelines
  - Install micro-generators in houses and use waste-heat for home heating
  - Side benefit: electricity and heat production trace each other in time, responding better to demand profile)
  - **Engineering research projects**

Research Opportunities

- Is there a way to extract bio-diesel?
  - Could avoid "net energy" pitfall, if extracted from biogas fermentation residue
  - Admixture of other enzymes/chemicals
  - **Chemistry/biochemistry research projects**

Research Opportunities

- Turn-key solutions for Michigan Farmers?
  - Possible MSU business spin-off
  - Aid with analysis of local conditions (distance to grid, land distribution, water availability, …)
  - **Business school research projects**
- Potential giant provable economic impact
  - PR possibilities endless