Biofuels and Bio-based Chemicals: Opportunities & Barriers

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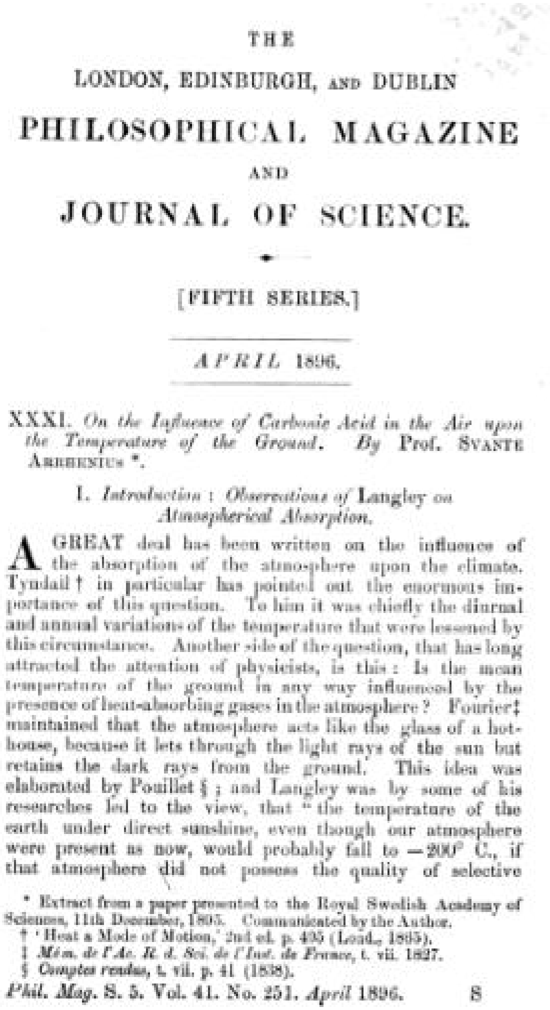
The way we produce and use energy today is not sustainable
A new direction is needed

The Effect of CO_2 on Global Temperatures isn't a Recent Discovery!



THE

LONDON, EDINBURGH, AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS *.

I. *Introduction : Observations of* Langley *on Atmospherical Absorption.*

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this : Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier ‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet § ; and Langley was by some of his researches led to the view, that "the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to −200° C., if that atmosphere did not possess the quality of selective

* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December, 1895. Communicated by the Author.
† 'Heat a Mode of Motion,' 2nd ed. p. 405 (Lond., 1865).
‡ *Mém. de l'Ac. R. d. Sci. de l'Inst. de France*, t. vii. 1827.
§ *Comptes rendus*, t. vii. p. 41 (1838).

Phil. Mag. S. 5. Vol. 41. No. 251. *April* 1896. 8

"For us, as a company, the debate about whether man-made climate change is happening is over.

The debate now is about what we can do about it. Businesses, like ours, need to turn CO_2 management into a business opportunity by leading the search for responsible ways to manage CO_2, and use energy more efficiently. But that also requires concerted action by governments to create the long-term, market-based policies needed to make it worthwhile for companies to invest.

With fossil fuel use and CO_2 levels continuing to grow fast, there is no time to lose."

Shell's position on Climate Change

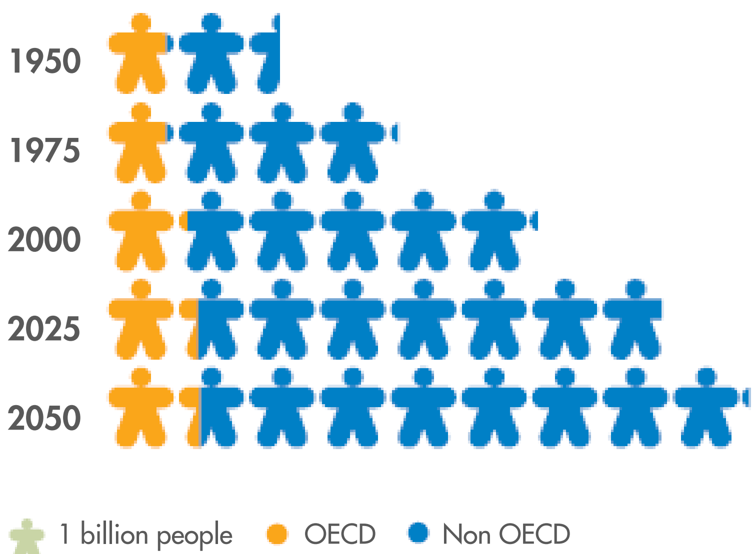
- Among first energy companies to acknowledge the threat of climate change
  - Take action ourselves!
  - Call for coordinated action by governments, industry and energy users

- Technology is a key enabler:
  - reduce CO2 emissions
  - Capture and sequester CO_2 from current energy systems & technology

http://www.shell.com/home/content/responsible_energy/environment/climate_change/

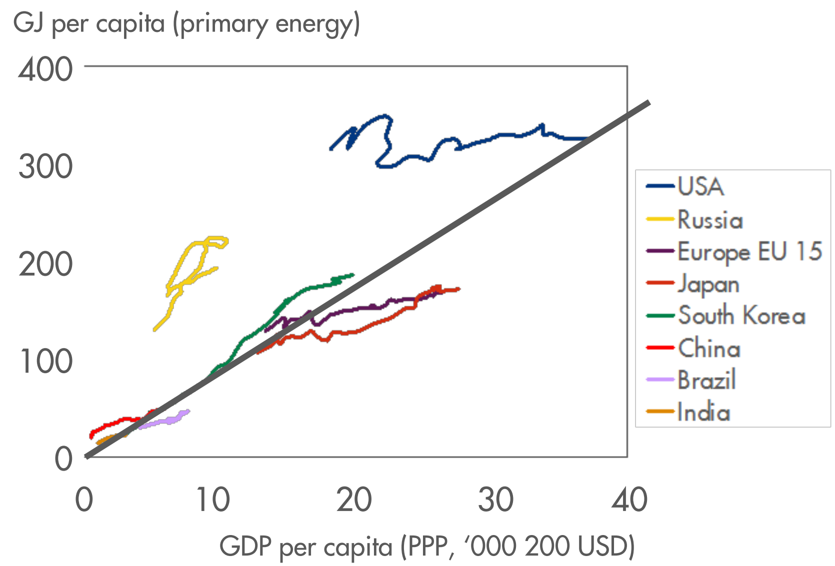
- Global demand for energy is growing.
- Supplies of “easy oil cannot keep up with demand growth.
- More energy means more CO_2 emitted at a time when climate change looms as a critical global issue

World population



Source: UN Population Division

Climbing the energy ladder



Data shown 1970-2005

Source: Energy Balances of OECD and Non-OECD Countries © OECD / IEA 2006

2- Scenarios

SCRAMBLE

- Policymakers pay little attention.
- Greenhouse gas emissions not seriously addressed
  – until major climate shocks.

BLUEPRINTS

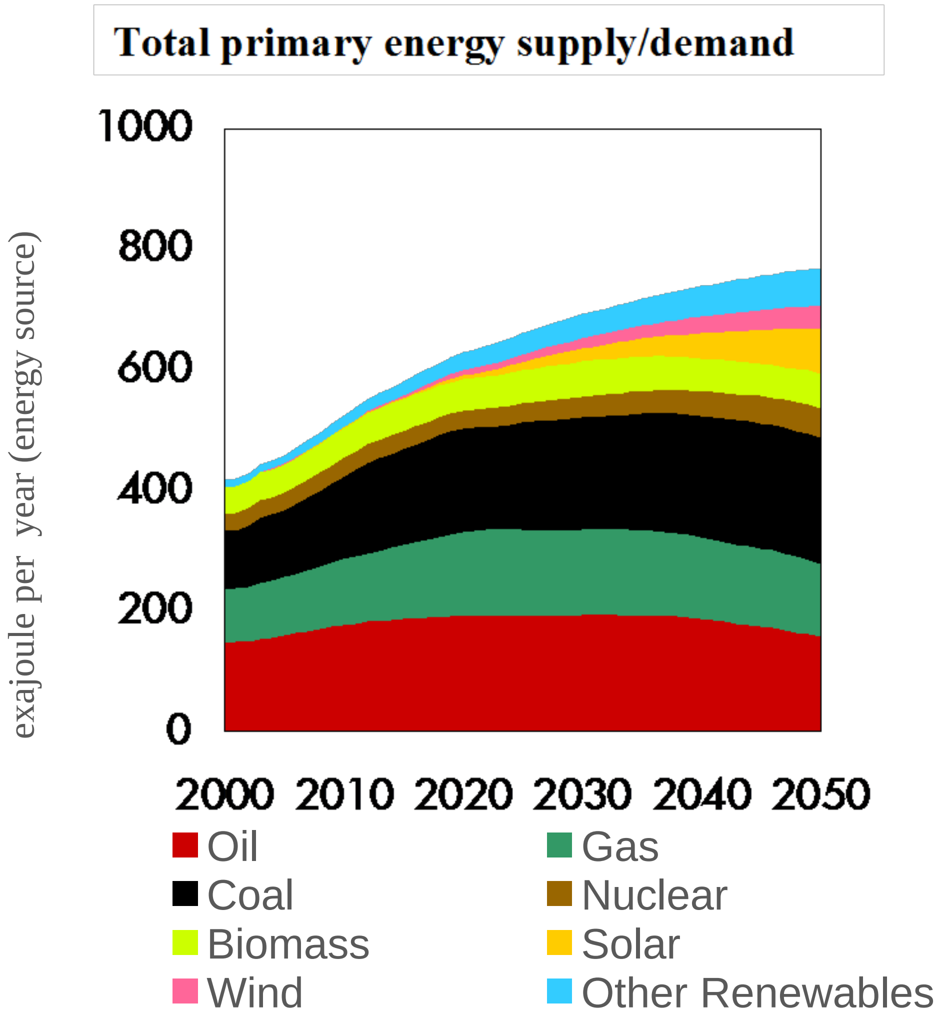
- Local actions begin to address the challenges
- Price is applied to emissions:

➔ stimulates development of clean energy technologies

- *CO2 capture and storage*
- energy efficiency
- Biofuels and alternative energy

"Blueprints" results in far lower CO_2 emissions.

Blueprints: What This Means for Energy

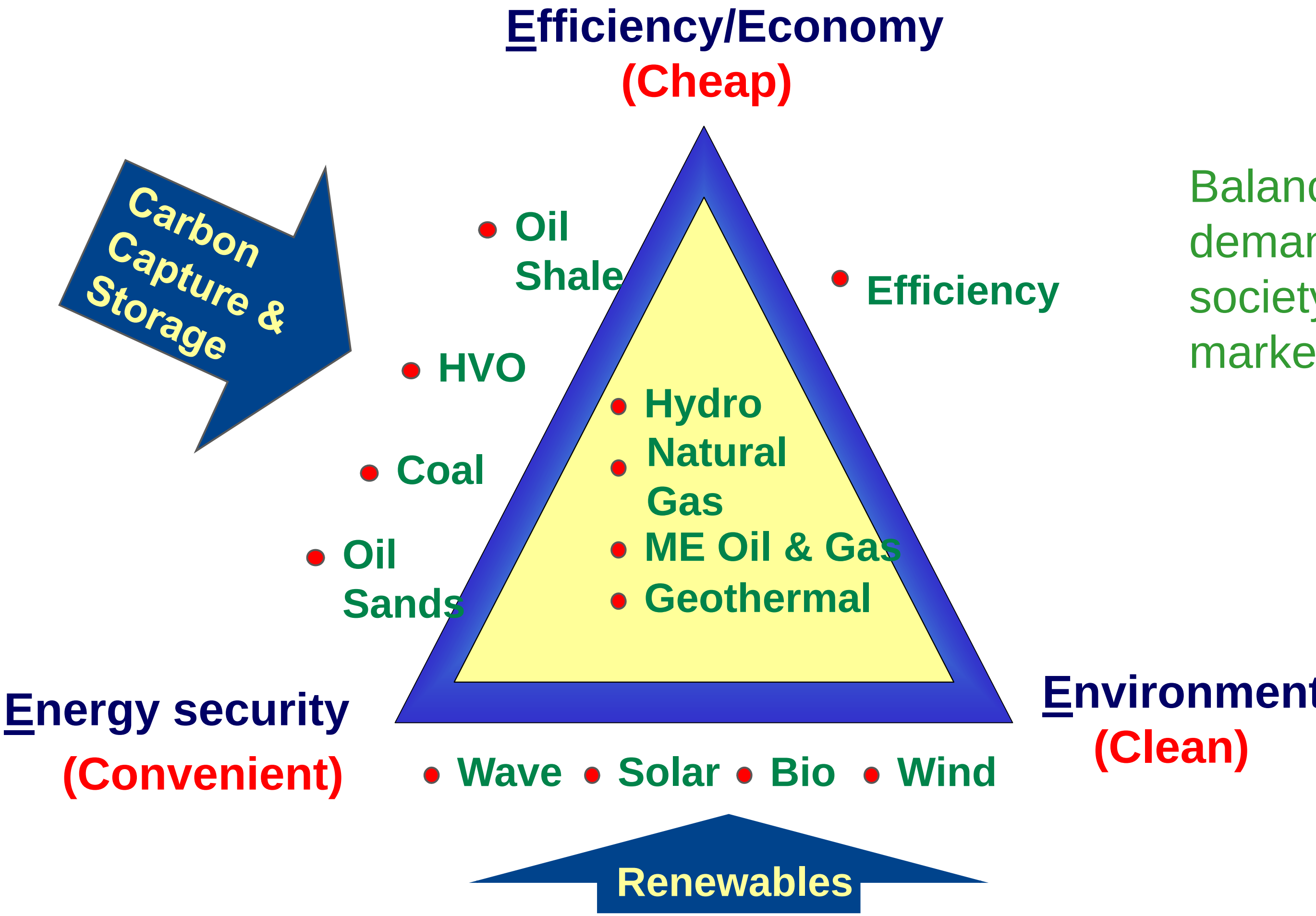


- Broader anticipation of challenges
- Critical mass of parallel responses to hard truths
- Effective carbon pricing established early
- Aggressive efficiency standards
- Growth shifts to electrification
- New infrastructure develops
- CCS emerges after 2020

Source: Shell International BV and Energy Balances of OECD and Non-OECD Countries©OECD/IEA 2006

The Energy Challenge Trilemma

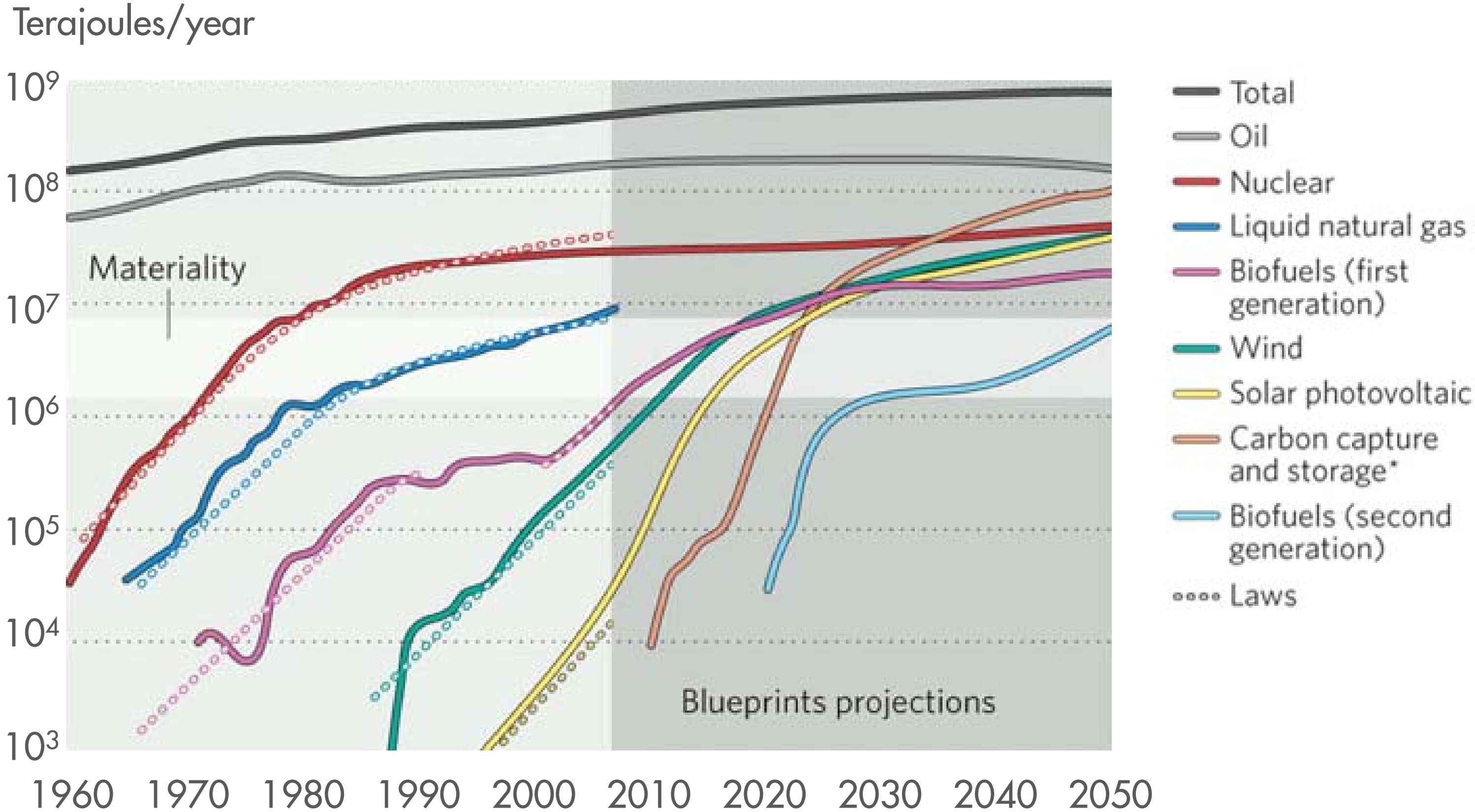
The "three C's" or "three E's"



Balancing demands of society and markets

ENERGY TECHNOLOGY CHANGE TAKES TIME

Global production of primary energy sources.



Source: Historic Data: Energy Balances of OECD Cuntries (IEA, 2009), Energy Balanaces of Non-OEDD Countries (IEA, 2009). Projections: Shell International, from the article: *No quick switch to low-carbon* energy by Gert Jan Kramer & Martin Haigh *Nature* 462, 568-569(3 December 2009)

*Coal and natural gas used in power generation with carbon capture and strorage

Shell: 30+ years GTL development

1973

Laboratory
Amsterdam
grams/d

1983

Pilot plant
Amsterdam
3 bbl/d

1993

Bintulu Malaysia
current capacity
14,700 bbl/d

TODAY

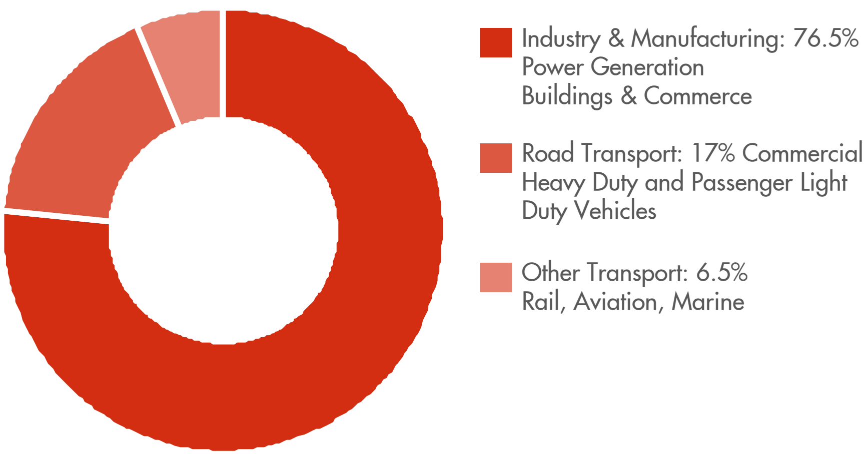
Pearl GTL Qatar
140,000 bbl/d

CONTINUED TECHNOLOGY DEVELOPMENT

TRANSPORT ENERGY DEMAND WILL INCREASE RAPIDLY

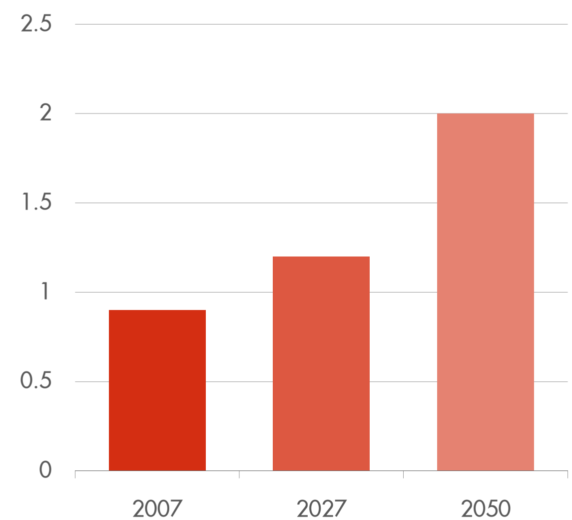
- *Energy-related* CO_2 emissions account for 62% of the global total
- Transport accounts for about 23% of *energy-related* CO_2 emissions. Road transport accounts for 17%
- Global population is growing and demand for mobility is increasing
- The number of vehicles on the road is expected to double to more than two billion by 2050

Energy Related CO_2 Emissions*



Source: International Energy Agency
* 62% of global CO_2 emissions

Estimate of worldwide vehicle demand



Source: World Business Council for Sustainable Development 2007

NO SINGLE ALTERNATIVE TO OIL BASED ROAD TRANSPORT FUELS

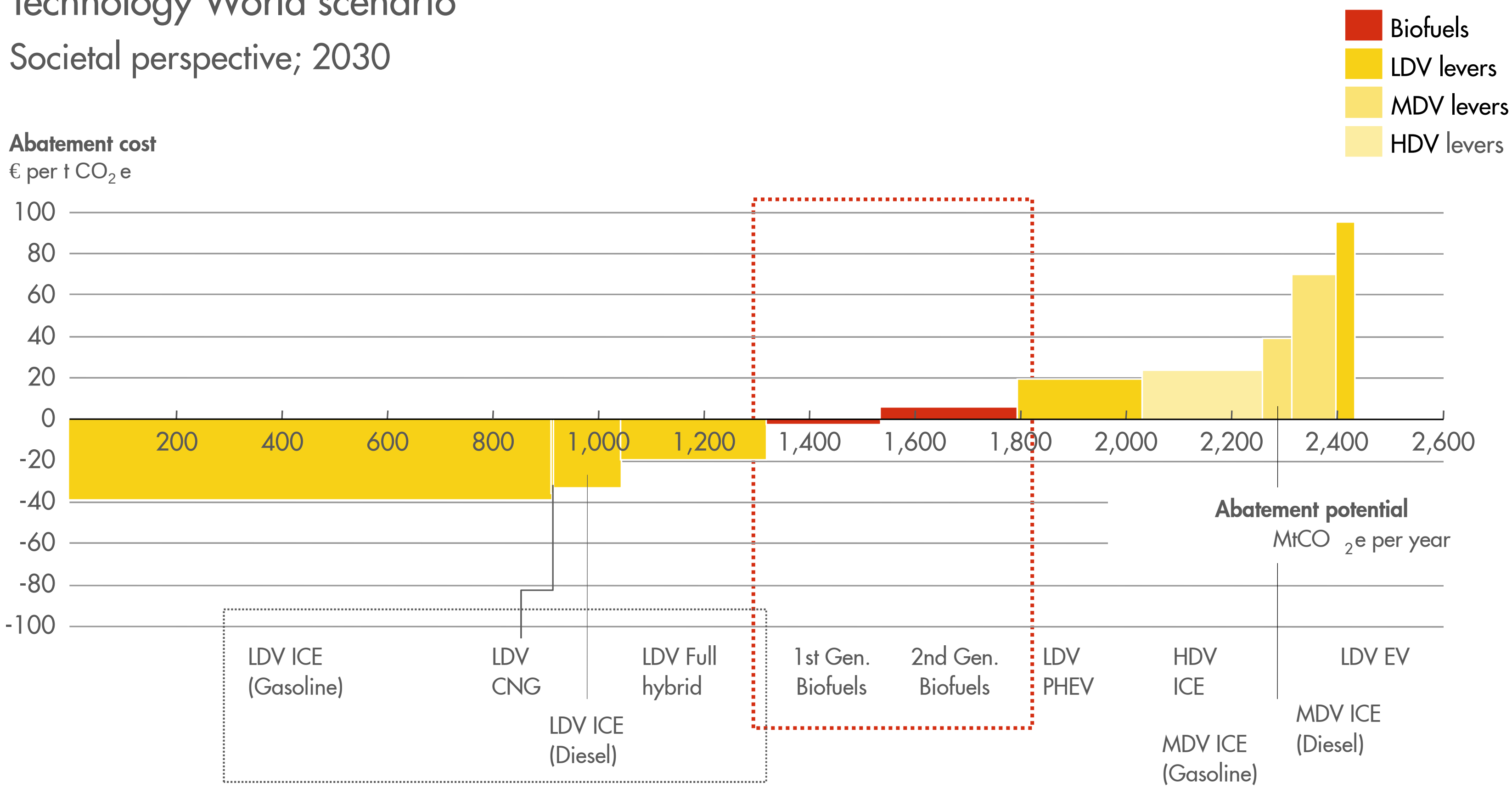
- All fuel options will be needed
- Countries and regions will choose portfolios of fuel solutions based on cost, security of supply, existing infrastructure and CO_2 emissions
- Not just fuels: Improvements in CO_2 emissions through vehicle efficiency, fuel technology and driving habits
- The internal combustion engine and liquid fuels will continue to play an important role
- Electric and hydrogen will play an important role if technical and infrastructure challenges can be overcome
- Natural gas will continue to find a niche in local markets

BIOFUELS AND EFFICIENCY: REDUCING CO_2 EMISSIONS TODAY

- Today's biofuels are the most realistic commercial solution to take CO_2 out of the transport fuels sector over the next twenty years

Global CO_2 abatement cost curve for the Road Transport sector - Mix Technology World scenario

Societal perspective; 2030



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €100 per t CO_2e in a penetration scenario if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

Source: Global GHG Abatement Cost Curve v2.0

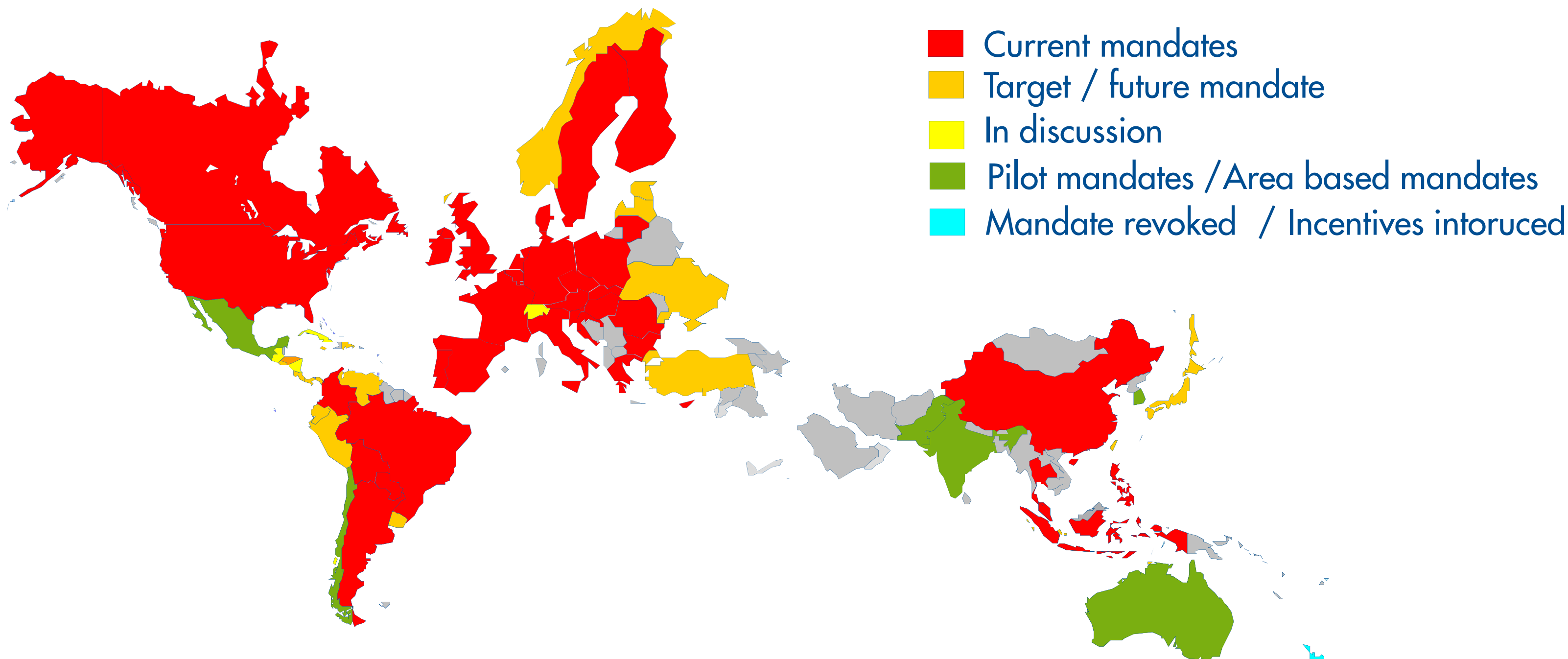
CO_2 Abatement Curve

Per-Anders Enkvist, Tomas Nauclér, Jerker Rosander, "A cost curve for greenhouse gas reduction", McKinsey Quarterly, 2007 (1).

Abatement costs ---	$/tonne of CO2 -----------
building insulation	-$183
commercial vehicles fuel efficienc	-$134
Lighting systems	-$113
air conditioning	-$110
water heating	-$70
fuel efficiency in vehicles	-$68
sugercane biofuel	-$17
industrial efficiency	-$14
Nuclear	$1
Livestock	$10
Forestation	$14
EOR with CCS	$21
Wind	$25
Cofiring biomass	$27
CCS with new coal	$28
CCS retrofit	$42
Biodiesel	$46

GOVERNMENT POLICIES CREATE A MARKET FOR BIOFUELS

- More than 65 countries have or are developing renewable fuels mandates
- Legislative priorities differ – energy security, support for domestic agriculture, environment
- Policies have created an international market for biofuels. Shell is working to meet obligations & benefit from opportunities
- The International Energy Agency has estimated that biofuels could represent 30% of the world's road transport fuel mix by 2050



TODAY'S ROAD TRANSPORT BIOFUELS

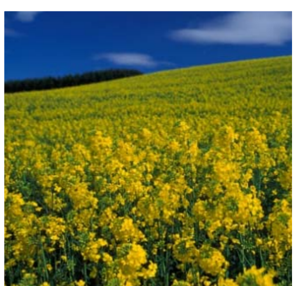
- The most widely used transport biofuels are ethanol and biodiesel
- Ethanol is usually made by fermenting crops high in sugar
- Biodiesel (FAME) is made from vegetable oil crops through transesterification
- Hydro-treating (HVO) uses a different process to biodiesel and can be blended at higher concentrations

Organic raw material


Sugar cane


Corn


Wheat


Rape seed


Palm oil


Soya bean

Process

Fermentation

Transesterification

Hydro-treating

Product

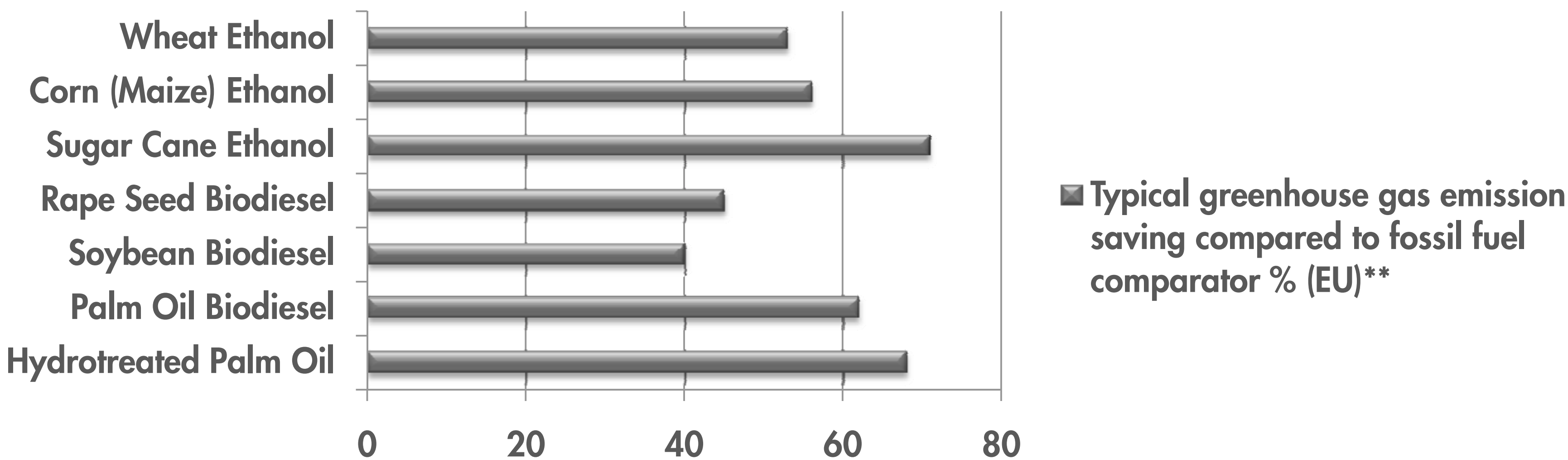
Ethanol (blend with gasoline)

FAME (blend with diesel)

HVO (blend with diesel)

BIOFUELS REDUCE CO_2 TODAY AND DIVERSIFY FUEL SUPPLY

- Biofuels are a low 'well-to-wheel'* CO_2 sustainable alternative to gasoline and diesel available today
- But CO_2 emission reductions depend on whole journey to combustion – feedstock production, process used, distribution and use in vehicles
- Biofuels diversify transport fuel pool and offer prospect of improved energy security
- Biofuels can be used in existing liquid transport fuel infrastructure
- For some countries biofuels can offer economic and rural development opportunities



*Well-to-Wheel CO_2 analysis calculates the CO_2 emissions relating to a particular fuel pathway. The calculation divides the pathway into two parts: (i) 'Well-to-Tank' (WtT) CO_2 emissions – from the production and distribution of the fuel feedstocka and the actual fuel (ii) 'Tank-to-Wheel' CO_2 emissions – from the use of the fuel in the vehicle
** Directive 2009/28/EC of the European Parliament and of the Council

SHELL: A LEADER IN TODAY'S BIOFUELS

- 30-year history of biofuels development and investment
- Growing investment in infrastructure to store, blend and distribute biofuels
- World's largest distributor of biofuels – 9 billion litres in 2010
- Building capacity in biofuels that provide best combinations of performance and low 'well-to-wheel' CO_2 performance from more sustainable feedstocks

Oil Products Value Chain: Upstream crude production → Refining and manufacturing

Biofuels Value Chain: Feedstock production → Bio component processing and manufacturing

Possible Shell involvement

→ Trading, storage and handling → Blending and distribution → Biofuel sales

Current Shell activity

Carson,
Los Angeles

Providence,
Rhode Island

Sewaren,
New Jersey

PROPOSED SHELL COSAN JOINT VENTURE

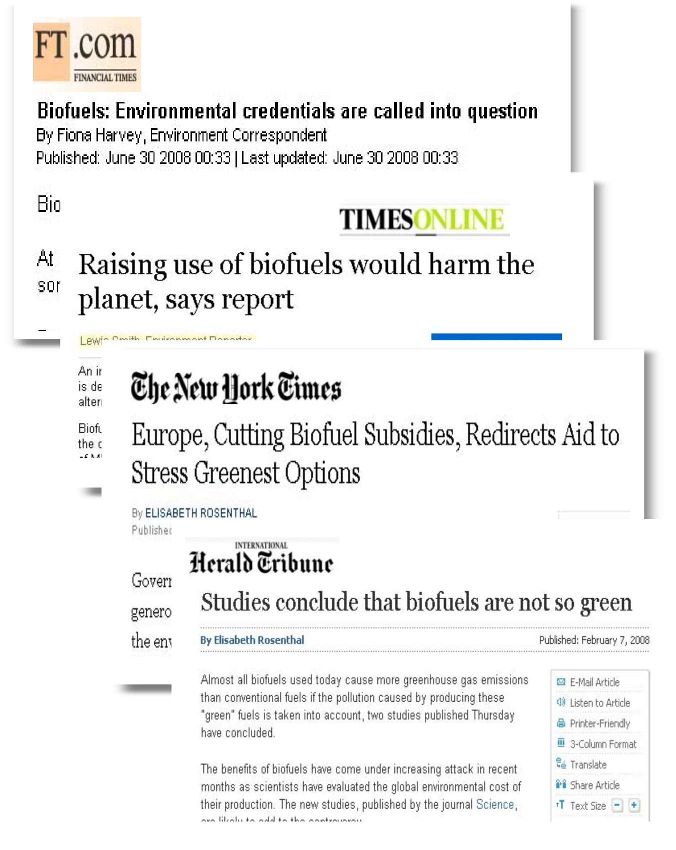
- Brazilian sugar cane – lowest CO_2 most sustainable and cost competitive of today's biofuels
- Non-binding Memorandum of Understanding with Cosan proposes $12 billion joint venture
- 2 billion litres of ethanol production capacity per year – with room to grow
- Robust sustainability principles, standards and operating procedures

Ethanol fuel in Shell's retail network


Automated sugarcane harvesting

TACKLING CO_2 AND SUSTAINABILITY CONCERNS

- A number of CO_2 and sustainability issues have been linked to the production of ethanol and FAME
- The 'well-to-wheel' CO_2 performance of biofuels can vary widely depending on the feedstocks and production and processing techniques used.
- Direct and indirect social and environmental impacts of biofuels production must be addressed
- There are a number of social issues linked to biofuels production, including workers' rights and local community land rights
- There are also environmental issues such as rare habitats and species, indirect land use change, soil and water, CO_2 emissions



PROMOTING CO_2 AND SUSTAINABILITY STANDARDS

- Advocating for the adoption of 'well-to-wheel' CO_2 standards to reward low CO_2 biofuels
- Need for a single robust approach for calculating 'well-to-wheel' carbon intensity of fuels
- Engaging industry, governments, intergovernmental agencies and policy makers to encourage sustainability standards in the biofuels supply chain
- Participating in industry initiatives working on voluntary guidelines for particular feedstocks
- Pledged support for international multi-stakeholder coalition seeking to enforce a moratorium on rainforest and peatland clearance for palm oil in Southeast Asia
- Working with the European Committee for Standardisation (CEN) to develop sustainability requirements in support of the European Energy Directive and Fuel Quality Directive

RSPO Roundtable on Sustainable Palm Oil

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

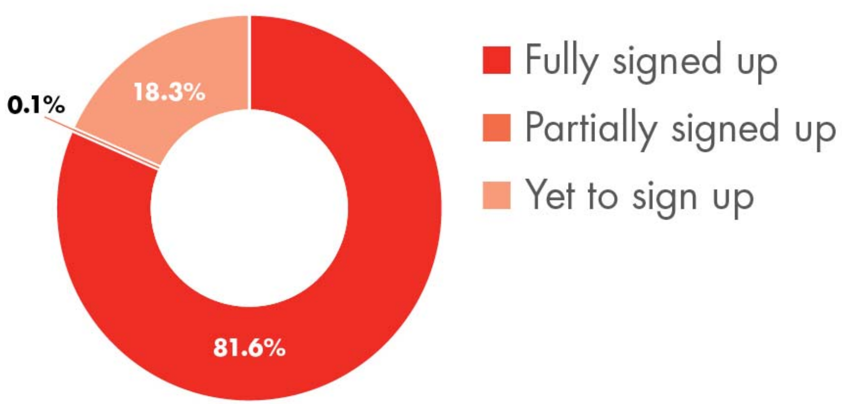
RTRS Round Table on Responsible Soy

BSI

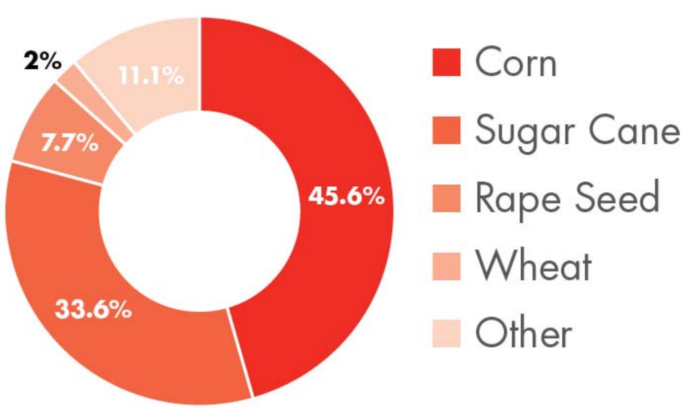
SUSTAINABILITY OF SHELL'S BIOFUELS SUPPLY CHAIN

- Championing sustainability standards in our own biofuels supply chain
- Rules and practices to help assess risks, implement controls, monitor compliance and report our progress
- Sustainability clauses in new and renewed term contracts:
  - feedstocks not knowingly linked to violation of human rights or produced in areas of high biodiversity value
  - suppliers develop and implement supply chain traceability systems
  - suppliers join relevant international bodies developing sustainability criteria particular feedstocks

Shell's Biocomponent Purchases Covered by Sustainabilty Clauses

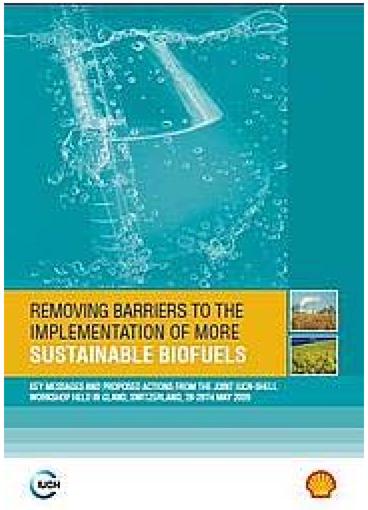


Shell Global Biocomponent Feedstock Purchase Q4 2009



WORKING WITH OTHERS TO PROGRESS KNOWLEDGE

- Working with environmental and social experts to develop projects to help address the potential direct and indirect impacts of biofuels
- Sharing experience and expertise
- Long-term collaboration with the International Union for Conservation of Nature (IUCN):
  - Addressing conservation and livelihood risks and opportunities in the biofuels supply chain
  - Providing opportunities for IUCN to influence global markets towards more sustainable biofuels production processes
- Working with other oil companies and NGOs including WWF and IUCN to investigate ways to promote sustainable production of biofuels feedstocks on underutilised or marginal lands

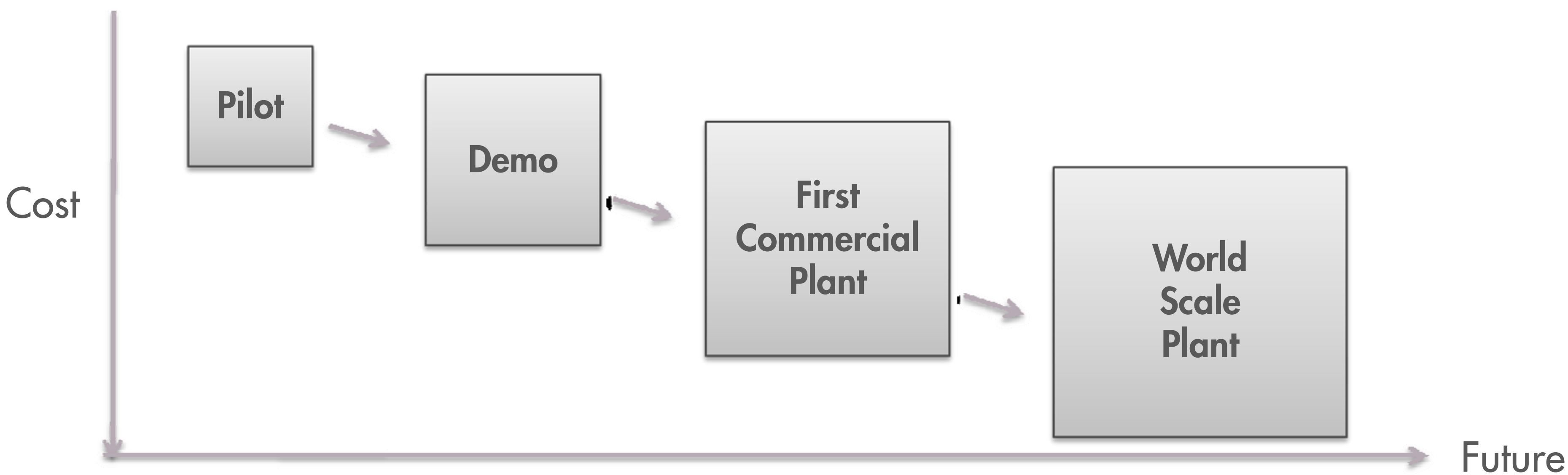


LEADING DEVELOPMENT OF ADVANCED BIOFUELS

- Advanced biofuels, using feedstocks such as crop wastes or inedible crops and new conversion processes
- Offer the potential for improved CO_2 reductions and improved fuel characteristics.
- Accelerating research, development and demonstration of advanced biofuels
- Dedicated Shell biofuels teams across 4 research centres in the US, UK, Netherlands and India
- Research agreements with experts in leading academic institutions across the world
- Technical partnership with leading biotechnology companies
- Our aim: to narrow down technology options to a feasible set of commercial solutions

ADVANCED BIOFUELS: COMMERCIALISATION AND ECONOMICS

- Shell is successfully progressing new technologies from lab-based process to demonstration phase and towards commercial scale-up
- Shell aims to narrow down advanced biofuels technology options to a feasible set of commercial solutions
- In the long term all biofuels will need to be cost competitive with all road transport fuels
- In the short term, government policies, incentives and financial support accelerate development from lab to commercial deployment



IOGEN ENERGY: CELLULOSIC ETHANOL FROM STRAW

- Shell and Iogen Corporation 50:50 equity partners in Joint Venture company Iogen Energy since 2002
- Joint technology programme developing the processing technology to make 'cellulosic' ethanol from lignocellulose (straw) using enzymes
- World's first commercial demonstration cellulosic ethanol plant opened in 2004 (Ottawa, Canada):
  - Produced more than 500,000 litres in 2009
  - Month long retail demonstration in Ottawa, June 2009
- CO_2 emissions of enzymatic cellulosic ethanol from straw could be up to 90% less than gasoline
- Full-scale commercial plant under assessment with focus on a site in Saskatchewan, Canada

IOGEN®
CORPORATION

CODEXIS: DEVELOPING NEW ENZYMES

- Shell has held a14.7% equity stake in Codexis, California since 2007
- Joint technology development programme to 'evolve' natural enzymes into improved variant enzymes capable of performing to specification
- Codexis is working closely with Shell and Iogen Energy to enhance the efficiency of enzymes used in the Iogen cellulosic ethanol production process
- Researching new enzymes to convert biomass directly into components similar to gasoline and diesel

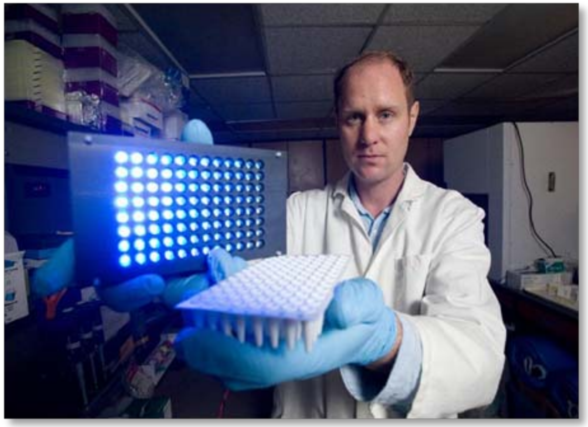
VIRENT: SUGARS TO HYDROCARBONS

- Joint technology development programme to convert plant sugars directly in to a range of high performance liquid transport fuels rather than ethanol, since 2008
- Uses catalysts to convert plant sugars into hydrocarbons
- Sugars can be sourced from crops and non-food sources
- Fuels have higher energy content than ethanol (or butanol) and deliver better fuel efficiency
- Could result in biofuels that can be used at high blend rates in standard gasoline engines
- Potentially eliminates requirement for specialized infrastructure, new engine designs and blending equipment

VIRENT

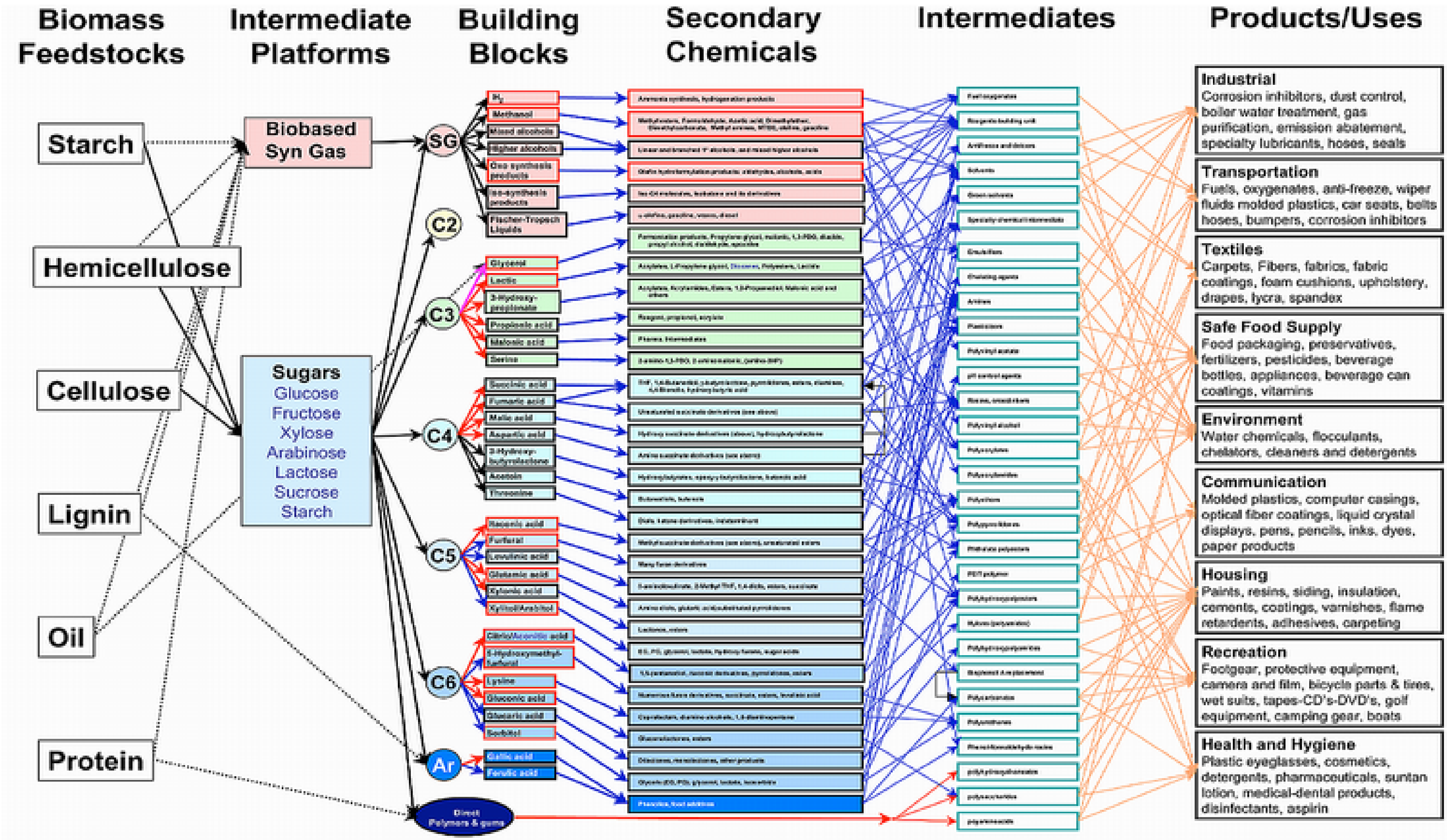
CELLANA: MARINE ALGAE FOR BIOFUEL

- Majority shareholder in Cellana since end 2007
- Joint technology development programme to operate a pilot facility in Hawaii to grow marine algae as a feedstock to produce vegetable oil for conversion into biofuel
- Algae hold great promise:
  - grow very rapidly
  - rich in vegetable oil
  - cultivated in ponds of seawater (minimising use of fertile land and fresh water)
- Academic research programme screening natural microalgae species to determine highest yields and most vegetable oil
- Long term potential to absorb or 'capture' waste CO_2 directly from industrial facilities such as power plants



CELLANA
ALGAE TECHNOLOGY. NATURALLY.

Chemicals from Bio-Based feedstocks



- Top Value Added Chemicals from Biomass: Volume I—Results of Screening for Potential Candidates from Sugars and Synthesis Gas Produced by the Staff at Pacific Northwest National Laboratory (PNNL) National Renewable Energy Laboratory (NREL) Office of Biomass Program (EERE) For the Office of the Biomass Program T. Werpy and G. Petersen, Editors, August 2004.

Growing tomatoes with refinery CO2

- CO_2 capture from refinery H_2 plant (Pernis Refinery, the Netherlands)
- Route to greenhouse: 2X increase in CO_2
  - 25% increase in tomato production rate
  - Implemented 2005
- "Organic CO_2" consortium
  - Cheaper than gas heaters to provide CO_2
  - Synergistic use of refinery offgas: 325,000 tonnes of CO_2 emission reduction.

C-Fix: a CO_2 value-added solution

C-Fix break-water armour units in IJmuiden, the Netherlands

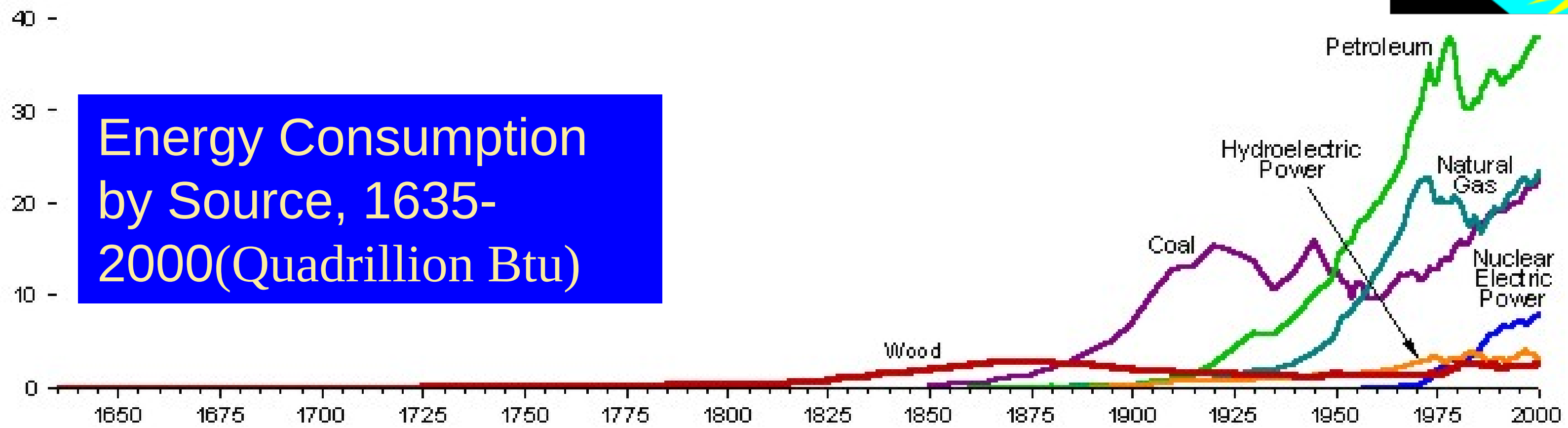
- Carbon-rich refinery residue
- Used as binder for “Carbon Concrete”
- 1 tonne cement binder prevents 2.5 tonnes of CO_2 emissions
- SO_2, NO_x, and CO emissions also reduced

SUMMARY

- There is no single alternative to oil based road transport fuels – all sustainable fuel options will be needed
- Today's biofuels are the most realistic commercial solution to take CO_2 out of the transport fuels sector and diversify supply over the next twenty years
- Shell is building capacity in biofuels that provide best combinations of performance and low 'well-to-wheel' CO_2 performance from more sustainable feedstocks
- Shell and Cosan have recently announced a proposed JV for the production of Brazilian sugar cane ethanol
- Shell advocates for the adoption of 'well-to-wheel' CO_2 and sustainability standards to reward biofuels that perform well
- Shell continues to invest significantly in advanced biofuels research and development and to work aggressively on commercialization.
- Basis for future chemical feedstocks will follow fuels into bio domain.

Challenges: Back to the Future for Energy

http://www.eia.doe.gov/emeu/aer/eh/frame.html



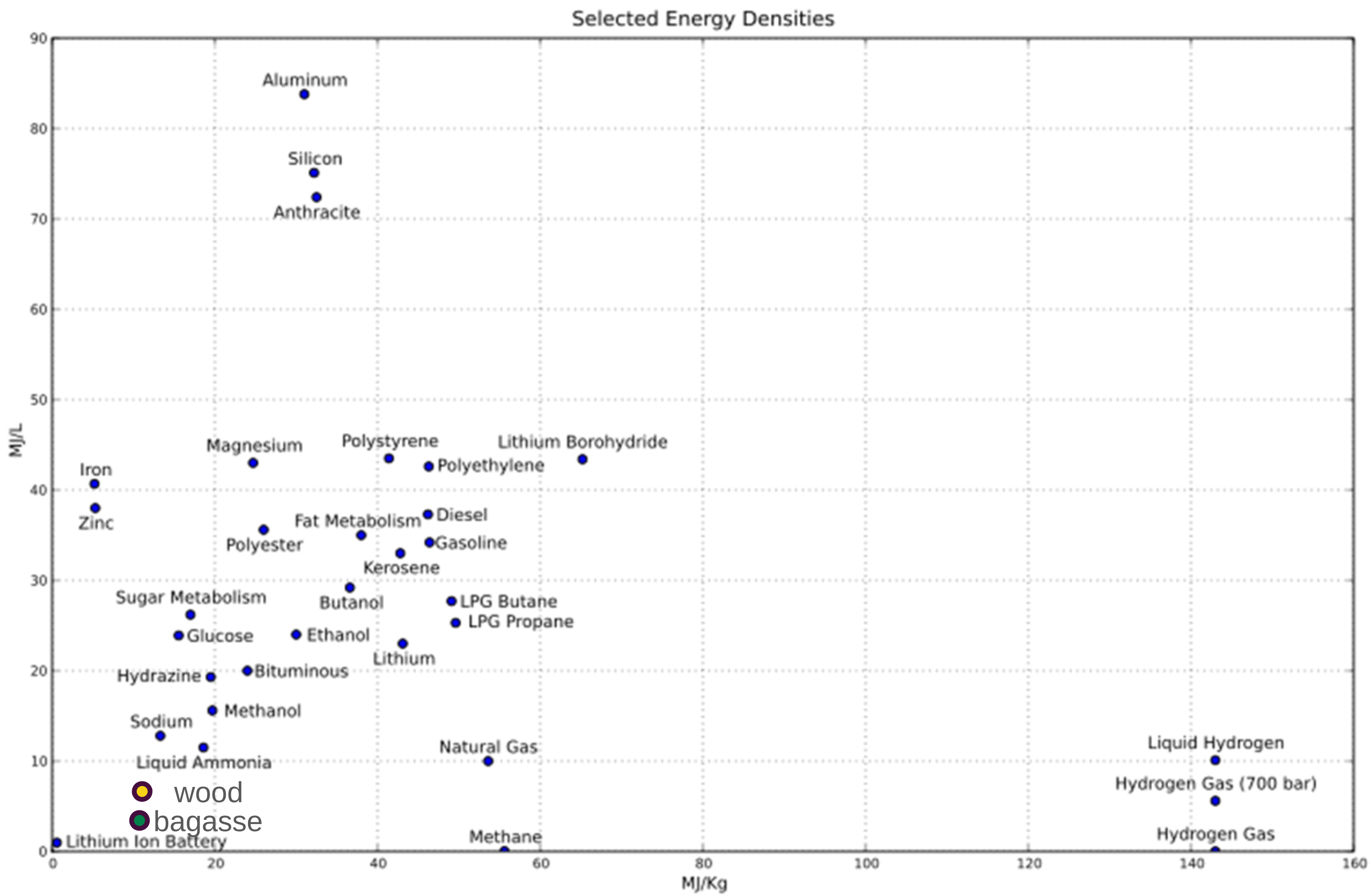
- Coal replaces woody biomass to start industrial revolution
- Steam replaces wind / clipper ships (1850's)
- Petroleum replaces coal as preferred transportation fuel (1900's)
- Electric / natural gas driers replace the solar clothes drier 1960

Petroleum & natural gas previously replaced the "alternative energies" we are now moving back to! Replacement was due to economics and convenience!

Sugar cane: Energy Density

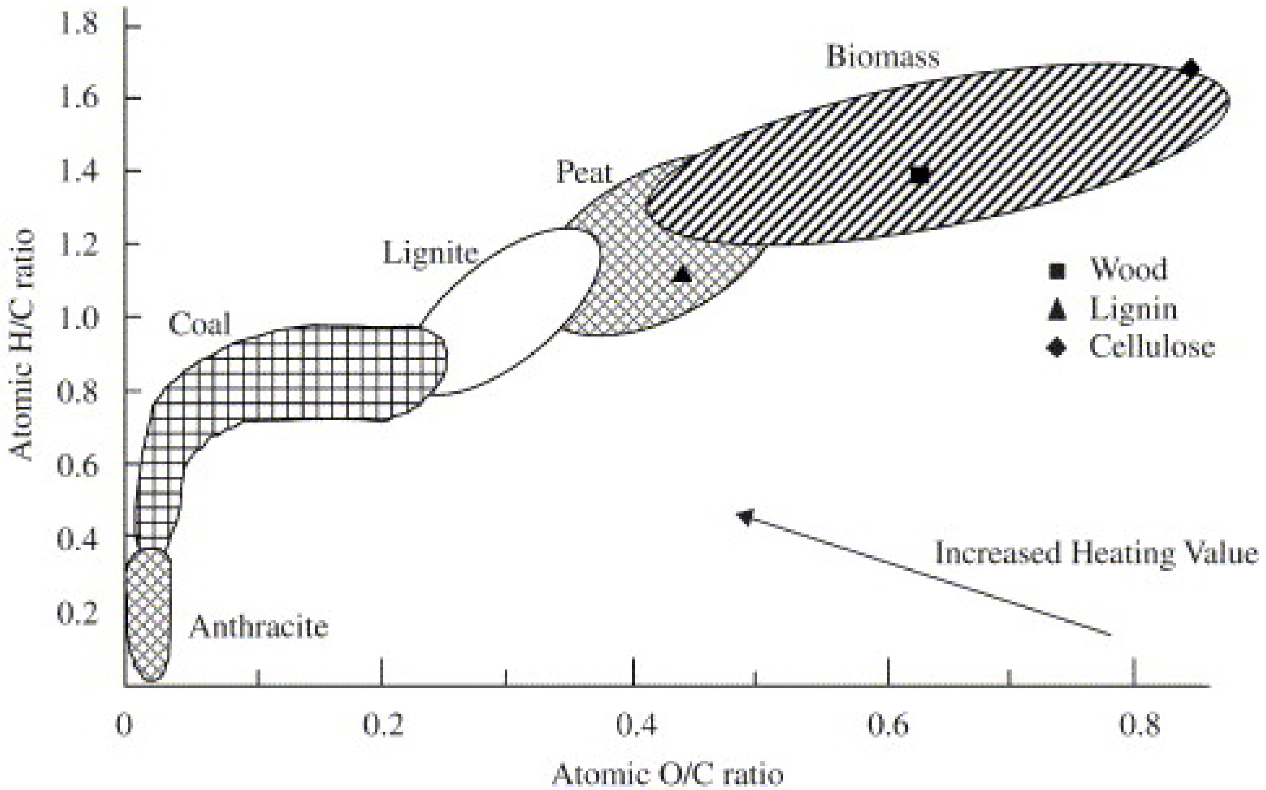
- Collection radius and transport efficiency

Energy Density: volumetric and mass



www.wikipedia.org

Oxygen content of Biomass



NTNU Combustion Handbook:
http://www.handbook.ifrf.net/handbook/cf.html?id=23

H/C ratio of fuels

Fuel	C-source	H/C
Methane (nat. gas)	fossil	4.0
Oil (gasoline US)	fossil	2.3
Oil Shale	fossil	1.4
Coal	fossil	0.8
Wood*	renewable	0.1

*80% cellulose 20% lignin - H2O

J. Ausubel and C. Marchetti, 1998

Biofuels & bio-based chemicals: Challenges and barriers

- Feedstock density
- Oxygen
- Water
- Timeframe for new energy infrastructure
- Sustainability