Making Vehicles Greener
Life Cycle Perspective

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1 – CSIRO, Australia

2 – OSAR, Ukraine

Challenges for Green Design

Challenge 1.

Inherent contradictions among social goals.

Challenge 2.

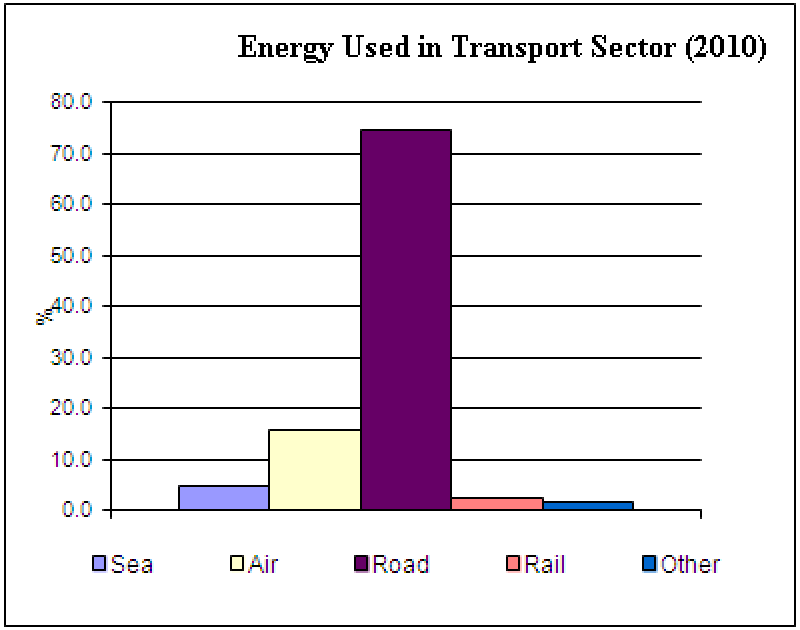
Difficulties in identifying and quantifying benefits” and “costs” to the environment and human health that stem from our inability to recognize some effects, our inability to quantify those that we can recognize, and finally, difficulties in valuation.

Transport Sector in Australia

- **The transport sector accounts for 35 per cent of final energy use and 70 per cent of liquid fuels used (including LPG) in Australia.**
- **Strong growth energy use in the transport sector is projected, by around 1.4 per cent a year over the long term.**

	Total CO2-e, Mt	**Share of total, %**
Manufacturing and construction	43 .7	7.8
Transport	80.4	14.4
Other sectors	20.1	3.6
Other	1.2	0.2
Total fuel combustion activities	359 .8	64.4
Fugitive emissions from fuels	31. 2	5.6
Total energy sector	391 .0	69.9
Total net emissions	559.1	100

Carbon dioxide equivalent emissions from the energy sector (2010)



Transport Sector in Ukraine

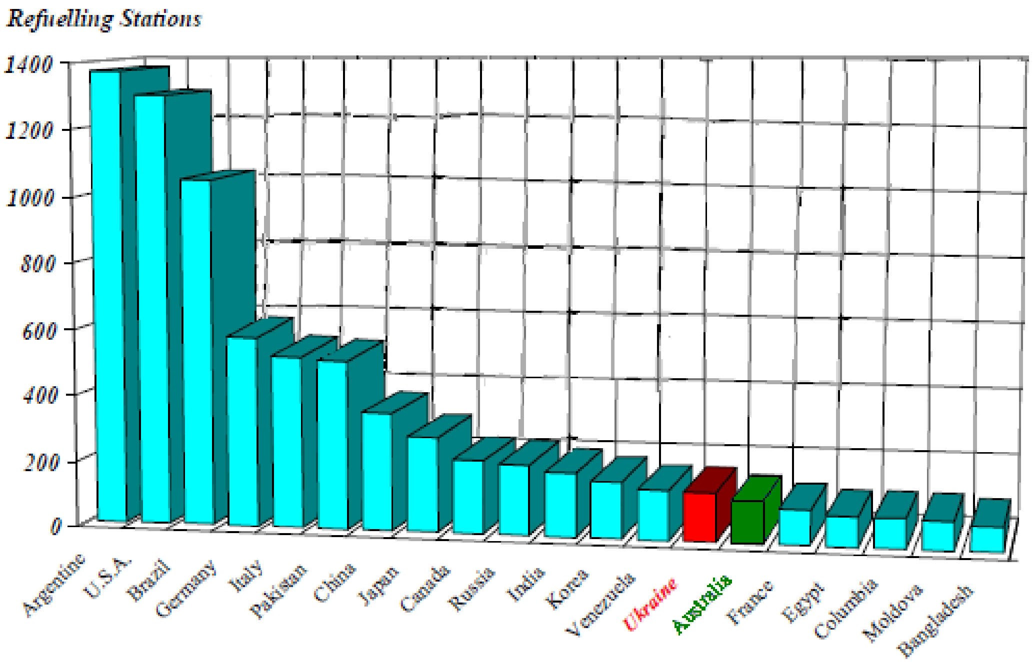
- More than 8 million automobiles (about 0.18 per capita).
- Road transport is the largest energy consumer within transport sector: (Growth 1.8% per annum over last 3 years)
- Automotive gasoline is the main fuel used by road transportation: (82.1 – gasoline; 17.9 - diesel)

	World	Ukraine	Australia	European Union	USA
Natural Gas	21%	41%	19%	22%	24%
Oil	35%	19%	32%	41%	38%
Coal	23%	19%	45%	16%	23%
Nuclear	7%	17%	-	15%	8%
Renewable	14%	4%	4	6%	7%
Total	100%	100%	100%	100%	100%

Primary energy consumption by different countries (2009-10)

Natural Gas – current situation

- **Australia - < 1% of current transportation fleet**
- **Ukraine - 2.2% of current transportation fleet**



Quantity of NG refuelling stations in Australia and Ukraine in comparison with other countries in the world

Oil as Fuel
Environmental Performance

- **The one of the major task for any country is securing its needs of energy sources (**The transportation is one of the major energy using sectors of an economy)

- **Considering the source of fuels, the transportation sector is the largest consumer of oil-based fuels (including gasoline, diesel, and other refined products).**

- **Burning oil-based fossil fuels significantly increases the level of carbon dioxide (CO2) and other pollution into the atmosphere (**particulate matter (PM), carbon monoxide (CO), hydrocarbons (HC), sulphur oxides (SOx), nitrogen oxides (NOx), and other air toxins)

- **Given the current situation, there is a need to assess the sustainability of predominantly relying on oil-based fuels versus other sources**

- ***The most attractive alternative to oil-based fuel currently is NG-based fuels***

Sustainability Assessment

- **The aim of this study is to make a comparison of possible sustainability benefits of using NG as a source of fuel for road transport in Australia and Ukraine** (Transport vehicles considered are passenger and light commercial vehicles)

- **Comparison of NG and current use of oil fuels is done based on environmental, economic, and social impacts**

  A) Environmental impacts include GHG and other pollutants

  B) Economic impacts assess use of gaseous fuels sourced domestically for Australia and supply by Russian Federation for Ukraine - versus oil-refined fuels (imported).

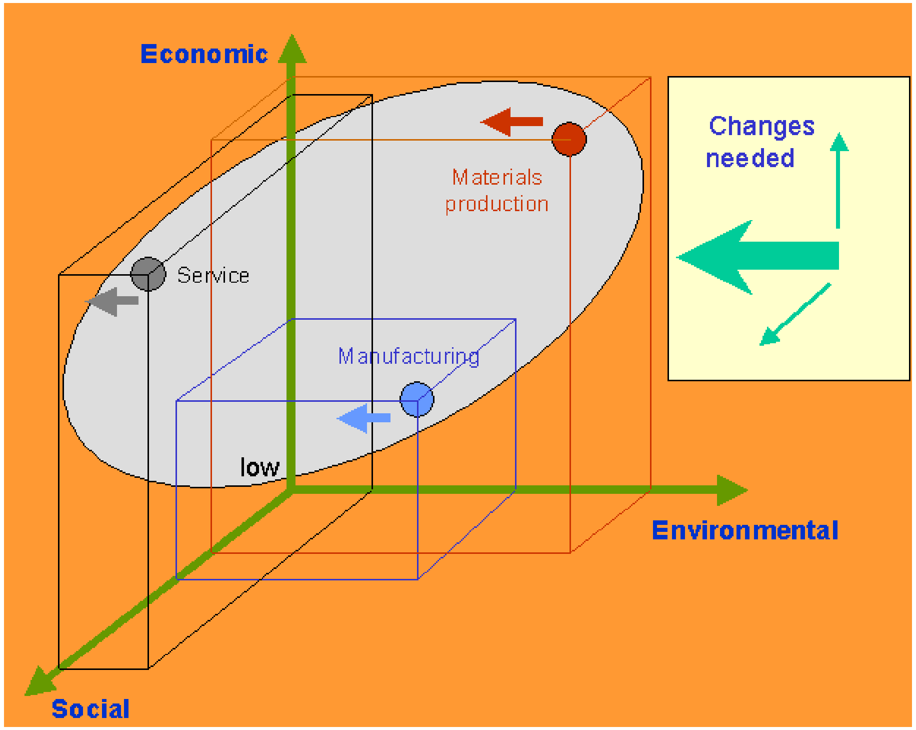
  C) Social impacts include pollution, safety, engine operation, as well as a shift of production capacities.

- **The comparison considers the whole life cycle of fuels (so-called "well-to-wheel" LCA) involving a sequence of stages, from the extraction of raw materials through to the combustion of fuel in vehicles**.

- **The geographic scope of this LCA study is largely limited to include only two countries: Australia and Ukraine.**

Sustainability Metrics

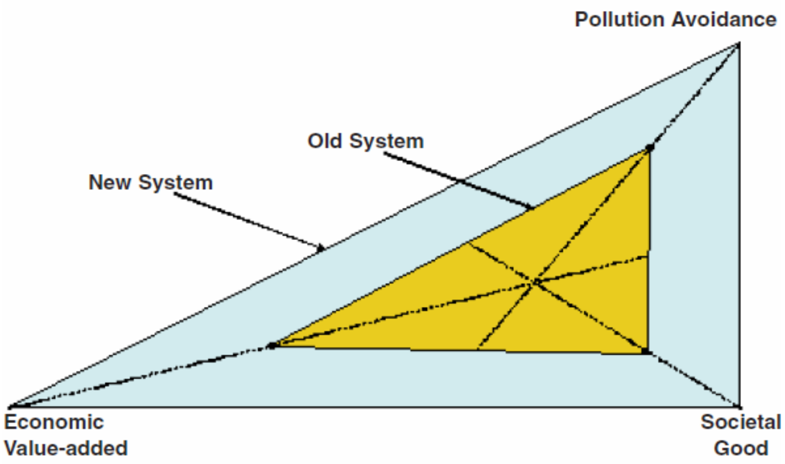
- **There are a number of methods used in presenting quantitative metrics for rating the performance of different types of transport** - Life Cycle Assessment (LCA) is currently one of the most popular methods aimed at quantifying the environmental effects related to a given product, process or activity along its life cycle



Triple Bottom Line Performance

The Scope of the Study

- **The sustainability assessment of different systems is an issue.**
- **However, it's possible to make a comparative assessment about state of the system to be more sustainable than another.**

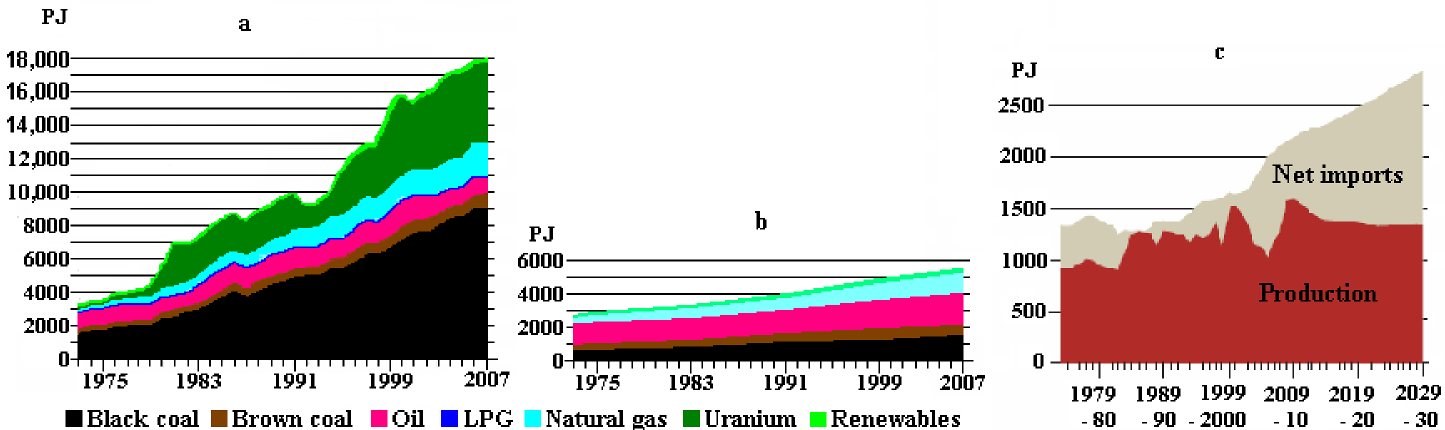


Complexity - requires multivariable assessment taking into consideration different aspects:

- global warming potential (GWP), Life cycle costs (LCC), net energy yield (NE), non-renewable resource depletion potential (NRDP)

Comparison - sustainability of road transport for Australian conditions using different type of fuels

Resource Depletion (Australia)



Energy production (a) and consumption (b) and oil production and consumption (c) in Australia.

	World		Australia	
	Oil	**N. Gas**	**Oil**	**N. Gas**
Proven reserve (kPJ)	5,770	5,740	8.770	152.0
Reserves to current production ratio (Years)	42	60	11	95

Proven oil and gas reserves

State	Current Production (PJ)	Potential consumption by road fleet (PJ)
NT	22	7.1
NSW +ACT	5*	307
QLD	139*	200
SA	124	71.4
VIC+TAS	312	343
WA	1141	107.1
Total	**1599**	**1035.6**

* Potential production are: 300PJ - for NSW; 700PJ - for QLD

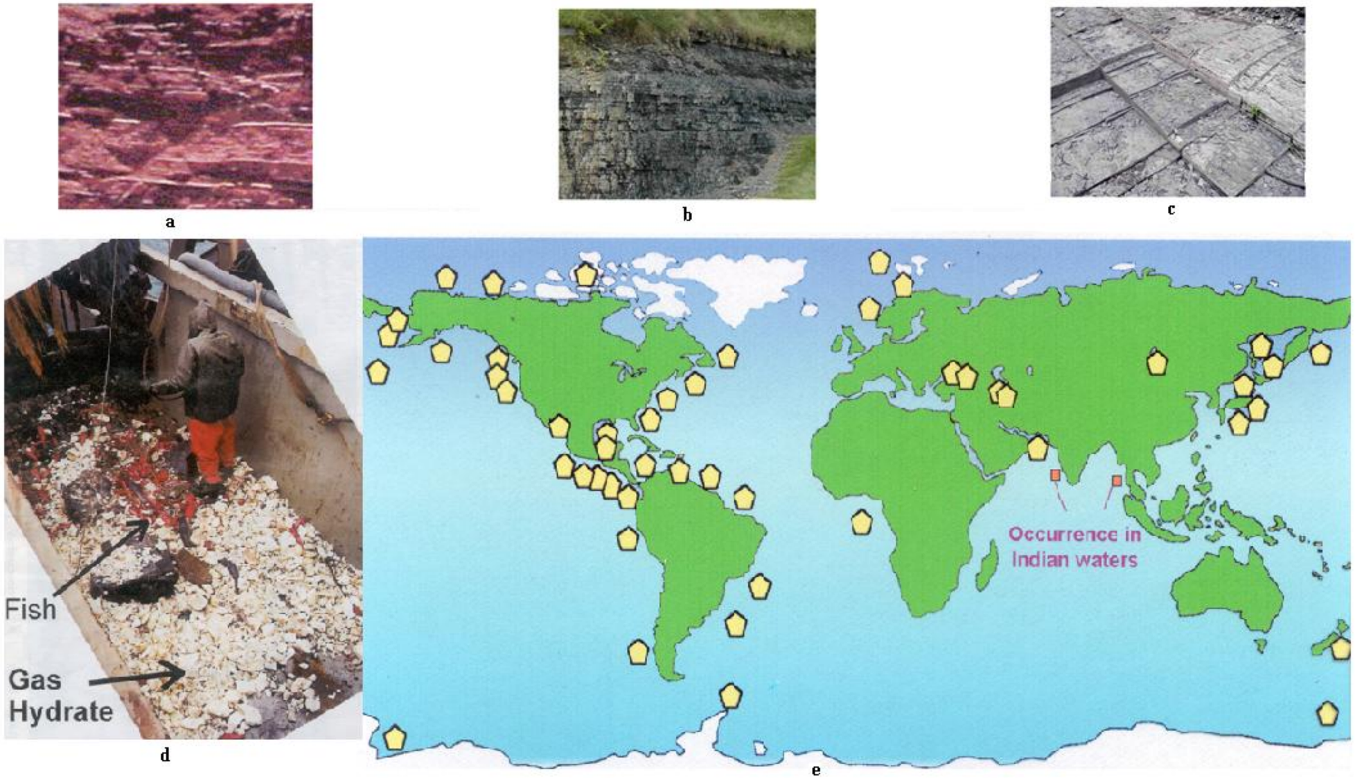
Production and potential consumption of N. gas as a transport fuel in each state

Resource Depletion (Ukraine)

Hydrocarbon Resources	Deposits		Potential Deposits
	Mined	Resources	
Natural Gas(NG), PJ	5,624	10,238	146,631
NG dissolved in oil, PJ	3, 569	4,362	11, 407
Oil, PJ	4,400	6,688	31,024
Gas Condensates, PJ	5,529	8,290	14,918
Coal Seam Gas (CSG), PJ	2,868	5,664	5,184
Offshore gas hydrates, PJ	-	-	up to 1,756,650

Proven oil and gas reserves in Ukraine

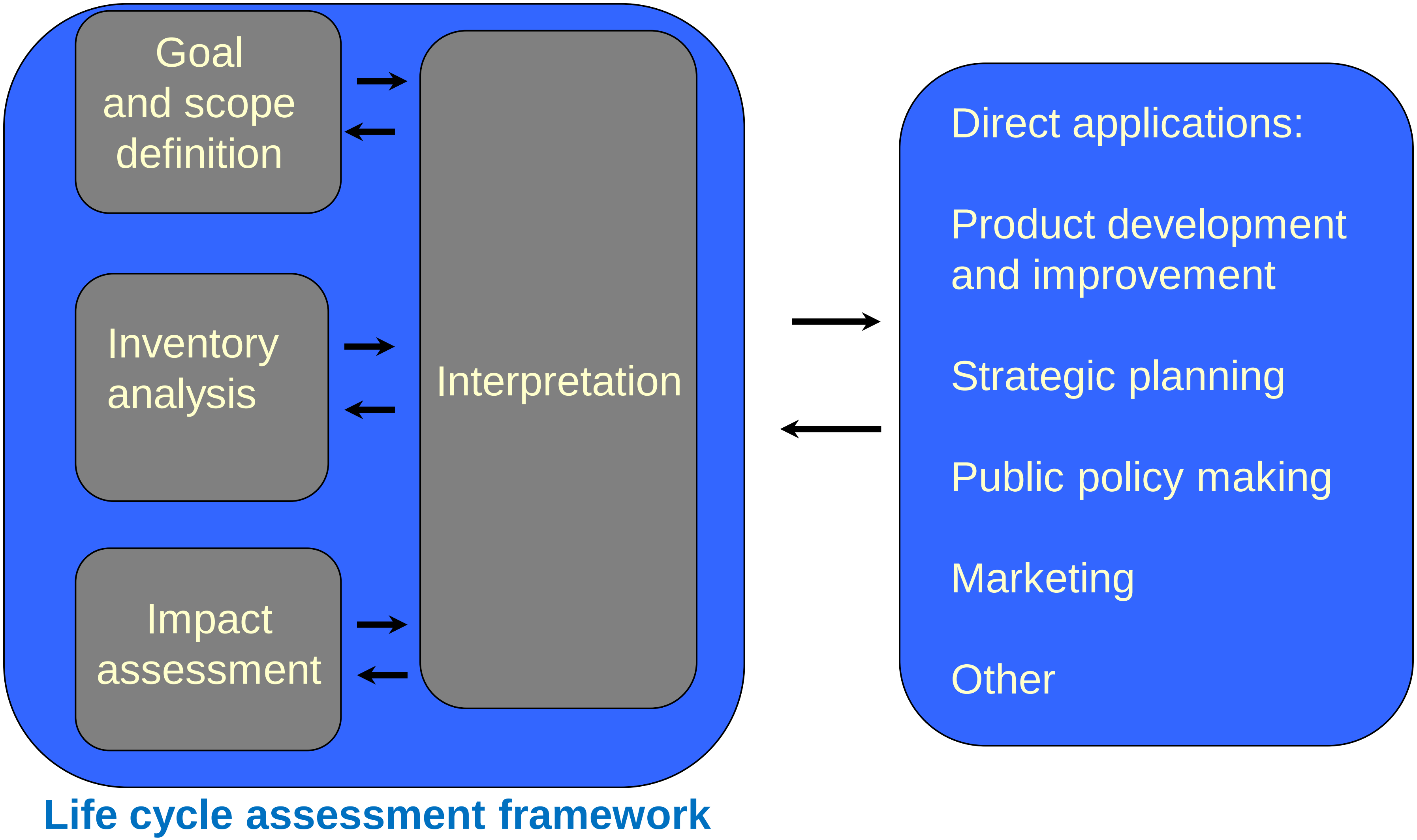
Resource Depletion



Non conventional reserves of NG: a) tight sands; b) coal-bed methane and coal mine gas; c) gas shells; d) gas hydrates; e) known occurrences of gas hydrates in offshore sediments

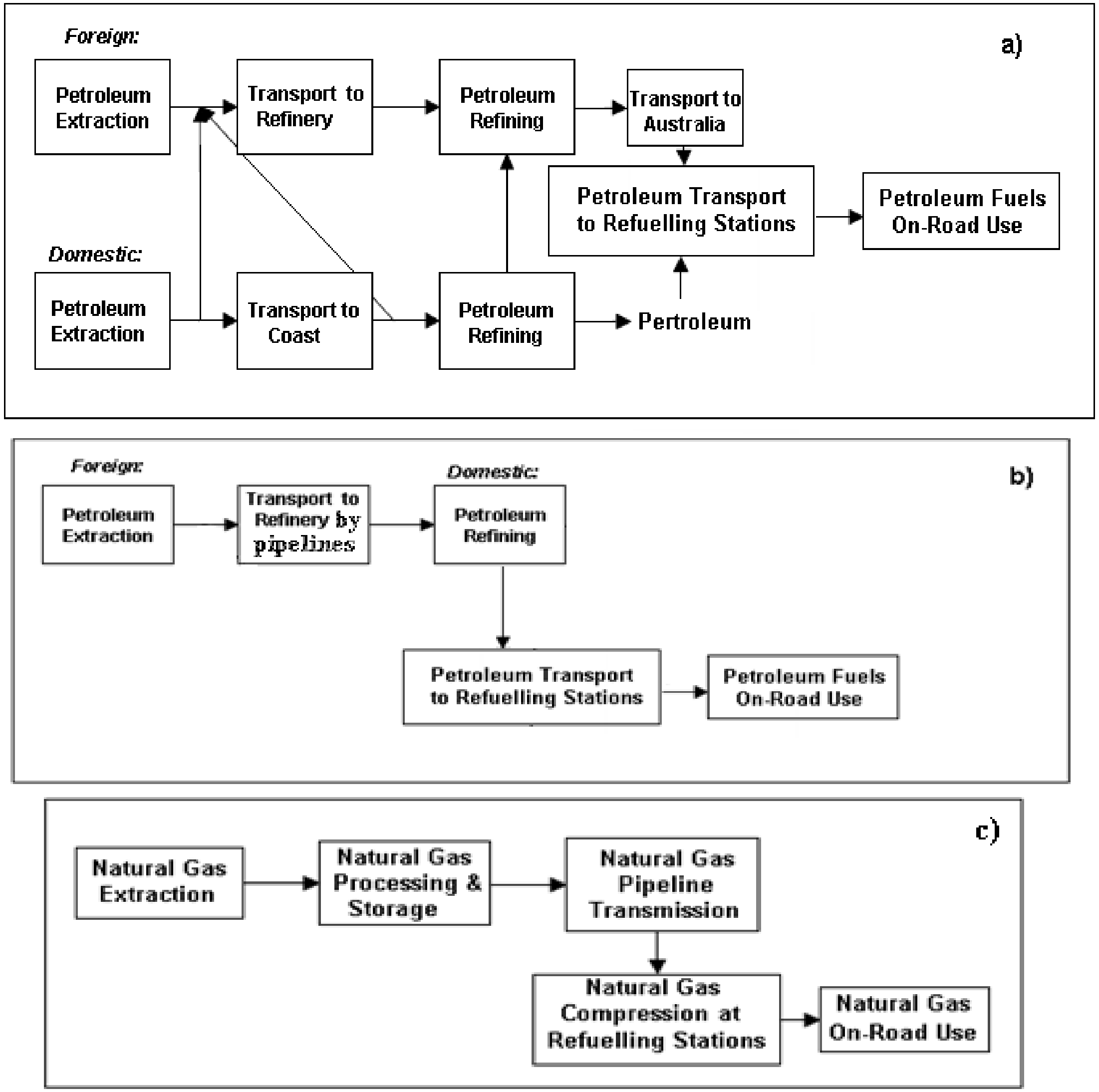
Gas hydrates has estimated reserve 10-20,000 times bigger than reserve of conventional NG i.e. bigger than all other fossil fuel reserves all together

Life Cycle Assessment (LCA) Study



Phases of an LCA Study (ISO 14040)

Life Cycle Environmental Impact: Oil-based Fuels vs. Natural Gas Fuel



System boundaries for the life cycle model of oil-based fuels in Australia (a), oil-based fuel in Ukraine (b) and NG fuel in both countries (c)

Well-To-Wheel LCA results for petroleum fuels in Australia

	Primary Energy input (MJ)	GHG emissions (kg of CO2 eq.)	Short description	Source
Exploration & extraction	79.7	2.08	Domestic (50%) + Foreign (50%)	[17]
Transportation to refinery	19.8	1.44	Domestic (50%) + Foreign (50%)	[17]
Refining	66.5	8.74	75% allocated to vehicles depending on oil-based fuel	[17]
Distribution to refuelling stations	30	2.61	10,000 Tanker (50%) + 1,000 km rail (50%) + 250km truck (100%)	[17]
Combustion in vehicles	1000	73.8		[18]
Total (without use stage)	**1196.0 (196.0)**	**88.67 (14.87)**		

Well-To-Wheel LCA results for petroleum fuels in Ukraine

	Primary Energy input (MJ)	GHG emissions (kg of CO2 eq.)	Short description	Source
Exploration & extraction	62.0	1.75	Domestic (20%) + Foreign (80%)	[16]
Transportation to refinery	4.72	0.34	Pipelines (20% - 300 km; 80% – 4000km)	[19]
Refining	66.5	8.74	75% allocated to vehicles depending on oil-based fuel	[17]
Distribution to refuelling stations	18	1.57	300 km rail (50%) + 150km truck (50%)	[17]
Combustion in vehicles	1000	73.8		[20]
Total (without use stage)	**1151.2 (151.2)**	**86.20 (12.40)**		

Well-To-Wheel LCA results for NG fuel in Australia

	Primary Energy input (MJ)	GHG emissions (kg of CO2 eq.)	Short description	Source
Exploration & extraction	74.9	5.29	Off shore extraction (Australia)	[20]
Reforming & storage	9.5	0.57	On shore processing	[21]
Distribution to refuelling stations	8.4	2.61	1500km on shore pipeline (pipelines installation, NG lost during extraction and transportation are included)	[20]
Compression for refuelling vehicles	60.0	3.04	Compression done by: engines 75%; turbines 25%	[18]
Combustion in specifically designed engines	1000	49.50		[15]
Total (without use stage)	**1152.8 (152.8)**	**61.01 (11.51)**		

Well-To-Wheel LCA results for NG fuel in Ukraine

	Primary Energy input (MJ)	**GHG emissions (kg of CO2 eq.)**	**Short description**	**Source**
Exploration & extraction	30.0	4.1	On shore extraction	[20]
Reforming & storage	9.5	0.57	On shore processing	[21]
Distribution to refuelling stations	22.4	6.95	4000km on shore pipeline (pipelines installation, NG lost during extraction and transportation are included)	[20]
Compression for refuelling vehicles	60.0	3.04	Compression done by: engines 75%; turbines 25%	[18]
Combustion in specifically designed engines	1000	49.50		[15]
Total (without use stage)	**1121.9 (121.9)**	**64.16 (14.66)**		

GHG Emissions Reduction Due to Substitution of Oil-Based fuels by NG

Replacement of petroleum with NG (%)	Australia		Ukraine	
	50	100	50	100
GHG emissions reduction, Mt	17.8	35.6	4.4	8.8
GHG emissions reduction, (% of overall emissions)	4.5	9.0	1.4	2.8

- **The actual reduction of GHG emissions could be higher than presented in Table if consideration of unconventional sources of NG would be included**.

Emission	Petroleum	Natural Gas
Volatile organic compounds (VOC)	48.8	20.5
Total particulate matter	79.8	5.81
SOx	346	100.9
NOx	1,865	200

Comparison of other air emission substances from "well-to-wheel" life cycle of petroleum fuel and NG

Estimation of Economic Impacts

Fuel	Australia		Ukraine	
	Fuel price (US$)	Price per 1GJ (US$)	Fuel price (US$)	Price per 1GJ (US$)
Firewood Domestic (Air dry)	250/ton	17.0	102/t	6.9
Black Coal	100/ton	7.0	100/t	7.0
Liquefied Petroleum Gas (LPG)	0.67/L	26.8	0.39/L	15.6
Compressed Natural Gas (CNG)	11.1/GJ	11.1	11.1/GJ	11.1
Petroleum	1.30/L	34.0	1.16/L	30.3
Electricity (tariffs)	0.18/kWh	50.0*	0.046/kWh	12.8*
Natural gas (tariffs)	0.013/MJ	13.0*	0.0028/MJ	2.8*

(* - All tariffs include supply charges for NG and electricity)

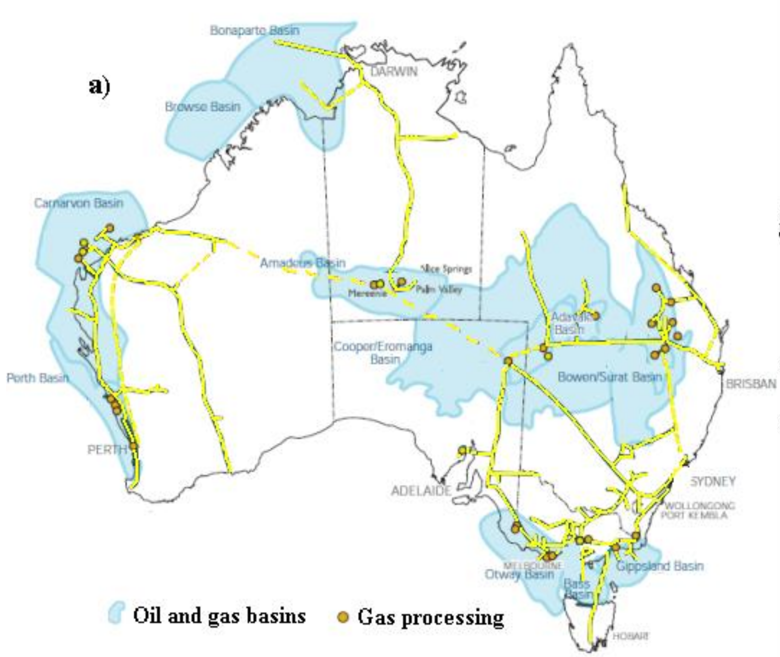
Prices for different energy source in Australian (August, 2009)

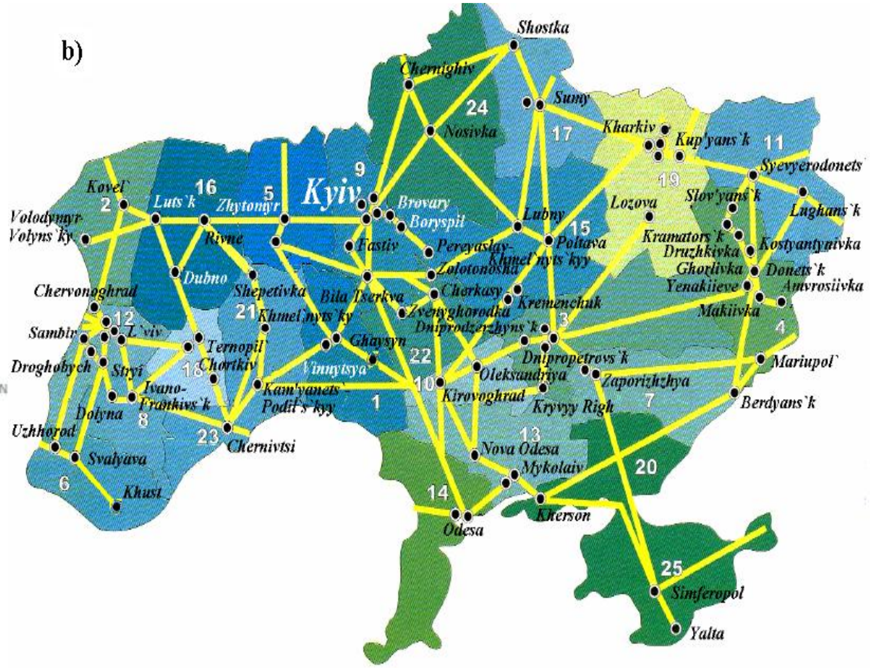
Fuel	Fuel price (US$)	Price per 1GJ (US$)
Oil	$578/ton	$13.6
LNG	$217/ton	$4.5

International price of oil and liquefied NG

Estimation of Economic Impacts (continue)

- **In case of oil-based fuel additional costs are incurred to convert oil to petrol and fuel distribution.**
- **The cost of distribution of CNG is lower than respective cost of oil-based fuels as it will be done though pipelines for both countries: Australia (a) and Ukraine (b).**





Estimation of Economic Impacts (continue)

Although oil-based fuels and NG prices are affected by many different factors it is possible to roughly estimate economic advantage due to replacement of oil-based fuels:

	Australia		Ukraine	
Replacement of petroleum with NG (%)	**50**	**100**	**50**	**100**
Estimated economic benefit in Australia, BUS$	7.5	15.0	2.53	5.12
Estimated reduction of fuel cost (%)	39.0	78.0	35.5	71.03

Estimated annual economic benefit in Australia and Ukraine due to replacement of petroleum fuels with NG

Additional economic advantages for NG as a transportation fuel may come from:

a) use of unconventional sources of NG (such as agricultural waste), which are cheaper than conventional NG sources and in most cases require less transportation due to local production;
b) unlike prices for oil-based fuels, which are highly volatile, the price of NG has been rather stable during past three years

Other economic benefits

- lower maintenance costs (natural gas burns clean);
- recent surveys found that NG engines require only
  check-ups after 160,000km
  and last up to 800,000km

1. Additional unconventional sources of NG (such as NG production from agricultural waste) will further down decrease the cost of fuel (as NG from those sources are cheaper to extract and requires less transportation due to local production).

2. Possibility to refuel vehicles from home, work, etc. using specifically designed compressors.

3. Indirect cost offset due to pull of the roads petroleum transportation fleet (NG will be mostly transported by pipelines).

Social Considerations for substitution petroleum fuels by natural gas

- **Social issues and values influence consumer acceptance of any product.**
- **It is the consumer that makes the ultimate choice when it comes down to the market acceptance of a new technology.**

For new vehicle technologies, two key areas were identified that require consumer acceptance: vehicle performance and refuelling.

Performance Criteria		Performance
Operation	Acceleration	Comparable performance
	Maintenance	Tends to be lower
	Distance between refuelling	Comparable with gasoline / Tends to be less than diesel
	Noise	Comparable performance
Safety	Toxic to skin and lungs	No
	Ingestion risk	No
	Temp req'd for spontaneous ignition	2.5 times higher
	Limits of flammability	Higher
Refuelling	Equipment	More complex
	Possibilities	Broader

Comparison of N. gas vehicle performance against gasoline ICEV

Other Social Considerations

Employment:

- considering the major players involving in developing new vehicle technologies and new fuelling infrastructures, it is obvious that many companies will be a part of such a transition;
- diversification of N. gas sources and suppliers may also see employment increasing.

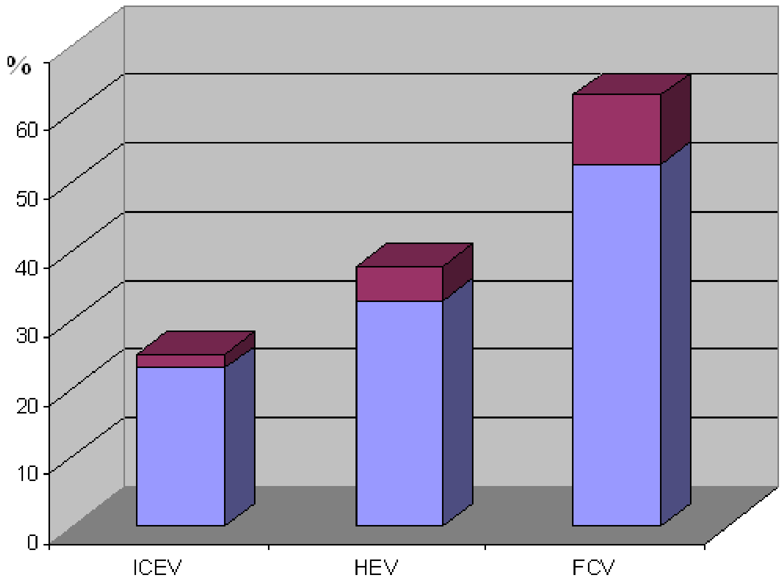
Safety:

- N. gas is a hydrocarbon fuel (predominantly CH4) which is lighter than air, colourless and odourless;
- leaking will rapidly disperse in the air, so that rapid combustion (explosion) is extremely unlikely, so it's an inherently safe fuel compared with other fuel;
- it's neither corrosive nor toxic and cannot contaminate soil or water.

Other benefits:

- **health -** N. gas uses as fuel is reducing air pollution and related public health risks;
- **economy - r**educing dependence on foreign petroleum and benefiting our domestic economy;
- **environment** - mitigating greenhouse gas emissions

Beyond Sustainability: Future road map



Comparison Vehicles Efficiency (Tank-to-Wheel)

Hybrid Electric Vehicles (HEV) - are inherently more complicated and expensive than conventional ICE due to their two or more sources of power and since they incorporate advances not currently utilized on conventional vehicles

Battery-Powered Vehicles (BPV) - are marketed as "zero emission vehicles" since they have no tailpipe and no vehicle emissions simply neglected other environmental, economic, and social aspects of sustainability.

Fuel Cell Vehicles (FCV) – are considered to be the most promising alternative but we are about 20yr away from having large numbers of these vehicles on the road.

Breakthroughs in fuel cell and hydrogen storage technologies and associated economics are required transition to a different fuel infrastructure result in significant challenges to commercialization of these vehicles.

N. gas could serve as a bridge to our energy future until cleaner fuel source (hydrogen) is more fully realized, as it's hydrogen by 80% chemically, has a similar to hydrogen physical properties and requires similar infrastructure.

Possible issues

Community Expectations

- For a new product or service to be successful, it requires not only consumer acceptance, but acceptance by the community or society.
- The impact of a new vehicle technology on the general public can be enormous, since vehicles and their supporting infrastructure are a large part of the daily life

Infrastructure Integration with Existing Infrastructure

- The integration of fuel distribution systems for natural gas with existing infrastructure will pose many technical challenges.
- At conventional refuelling stations, storage tanks for natural gas will need to be added, along with any equipment required for on-site gas compression.

Vehicle Costs

- The cost of the vehicle is the largest single cost for the consumer to consider when selecting a vehicle and this will play a significant role in the consumer acceptance of a new vehicle technology.

Further Work and Study

✓This is only preliminary study and it has been demonstrated that a life-cycle approach is needed to evaluate the overall road transportation system performance. The full study can provide important next steps in the advancement of vehicle and fuel supply systems.

✓A detailed investigation of the operating requirements and opportunities for design flexibility for N. gas refuelling stations and associated compression and storage equipment should be undertaken.

✓A full transportation system analysis should be performed. This would include aspects of transportation modes, and consideration of transportation objectives in order to consider how personal vehicle and fuel-supply systems fit in.

The results from this work should be utilized to assist in developing appropriate strategies and pathways for moving to the most environmentally, socially and economically sound transportation system and to assist in designing and implementing appropriate public policy incentives to move towards the best transportation system.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Comparison Natural Gas and Oil as Fuel
Environmental Performance (Well-to-Wheel)

The Civic GX is available in the US and various Asian countries where natural gas is an accepted vehicle fuel. This year the GX has once again topped the American Council for an Energy-Efficient Economy annual Greenest Cars List beating 4 petrol/electric hybrids including the Civic and Prius hybrids.

Obviously the lack of CNG refuelling limits long distance driving but with the Phill there are no such limitations for fleet use or doing the daily drive to and from work and down to the shops. If you've got natural gas piped to your home you'll never have to go to a service station again. You just plug it in over night and the tank fills up while you sleep

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Thank You

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