Lecture 20A & 20B

Energy Resources, Economics and Environment

Primary Energy Analysis

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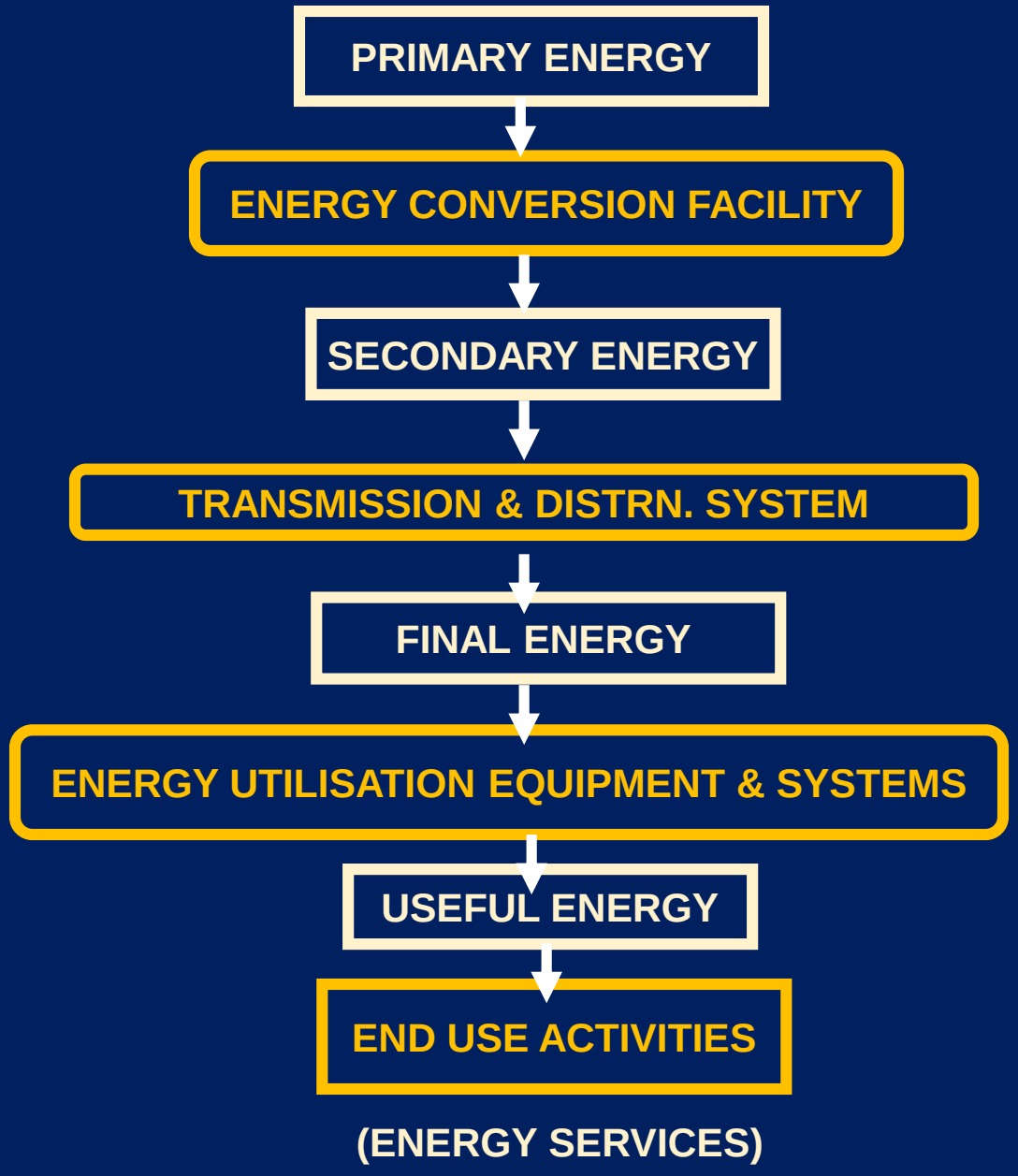
ENERGY FLOW DIAGRAM



COAL, OIL, SOLAR, GAS

POWER PLANT, REFINERIES

REFINED OIL, ELECTRICITY

RAILWAYS, TRUCKS, PIPELINES

WHAT CONSUMERS BUY DELIVERED ENERGY

AUTOMOBILE, LAMP, MOTOR, STOVE

MOTIVE POWER
RADIANT ENERGY

DISTANCE TRAVELLED, ILLUMINATION,COOKED FOOD etc..

Energy End Uses

End Use	Energy Service	Device
Cooking	Food Cooked	Chullah, stove
Lighting	Illumination	Incandescent Fluorescent, CFL
Transport	Distance travelled	Cycle, car, train, motorcycle, bus
Motive Power	Shaft work	motors
Cooling	Space Cooled	Fans,AC, refrig
Heating	Fluid heated	Boiler, Geyser

Decision Types / Perspectives

- System selection
  Yes/No
  Best possible amongst options
- System / Component Design
- Decide Operating Strategy
- Decide Policies

- End Users
- Manufacturers
- Utility
- Society / Government
- Others

Criteria

- Cost - Initial Cost, Operating Cost, Life Cycle Cost
- Reliability-Availability, Unmet Energy
- Emissions - Local, Global
- Sustainability
- Equity

Primary Energy Analysis

Compare options based on primary energy input

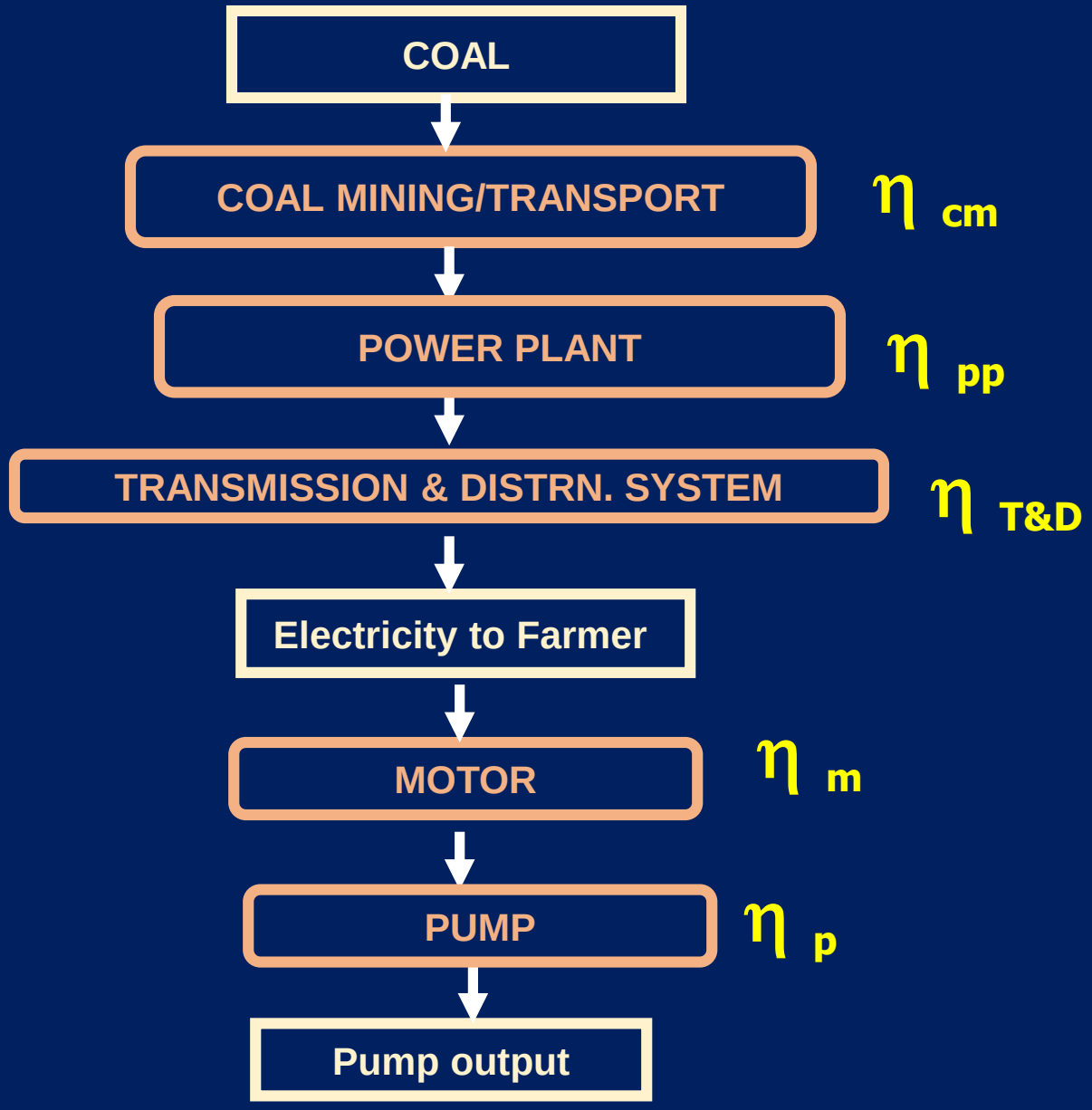
Primary Energy Analysis

- Water pumping- a) Grid Electricity
  b) Diesel Engine Pump
  c) Gasifier=Engine –pump
  d) Solar PV pumping
- Cars/ Buses a) IC engine vehicle (Diesel)
  b) Fuel Cell- Hydrogen
  c) Electric Vehicle- Grid Elec
  d) Biofuels

Primary Energy Analysis

- Compare options based on primary energy input
- Example : Agricultural Water Pumping
- 3 GJ of end-use /year (typical value)
- Options
  - A) Electric motor-pump
  - B) Diesel engine-pump
  - C) Biomass Gasifier-Dual fuel engine-pump

A)ELECTRIC MOTOR



η_{cm}

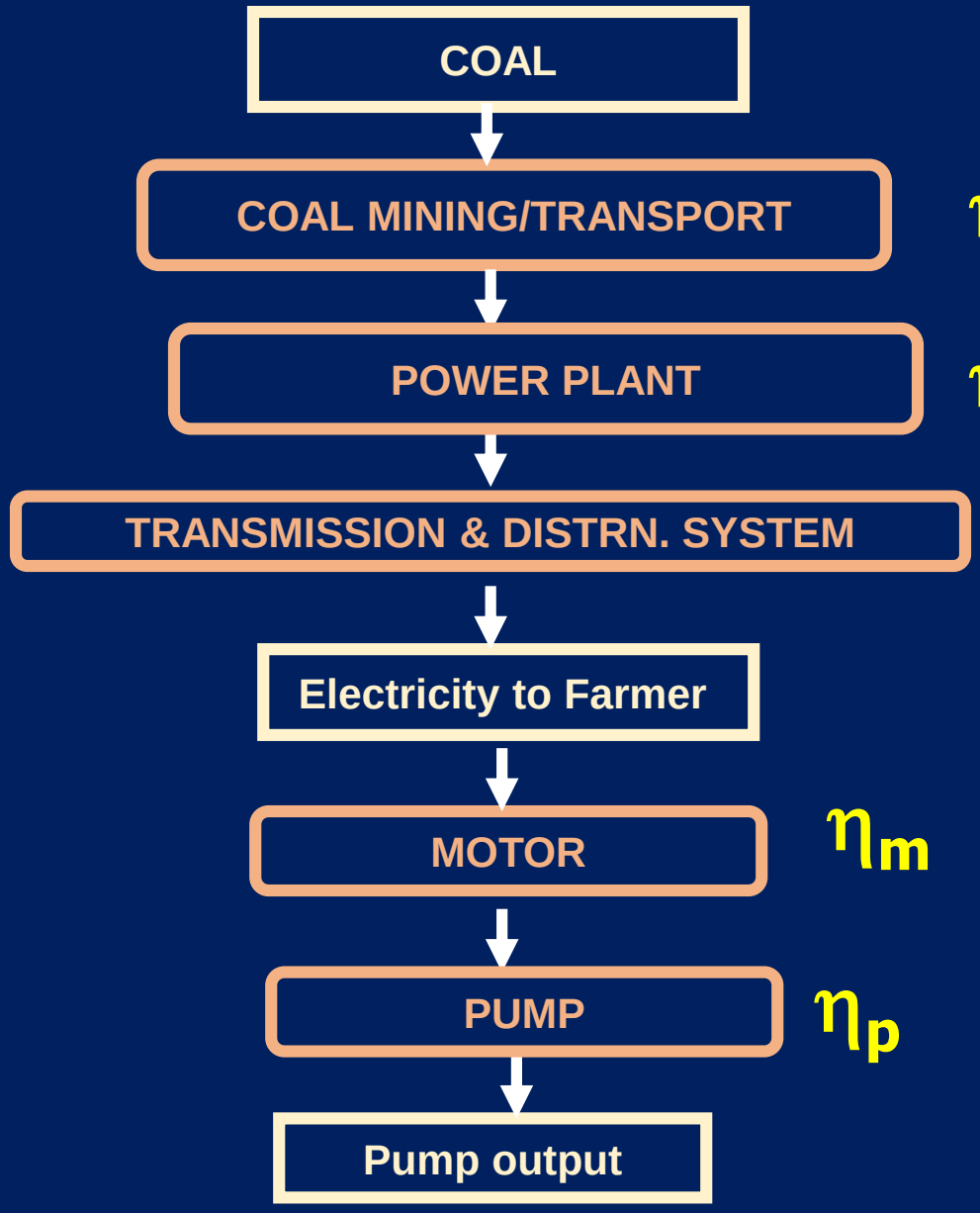
η_{pp}

$\eta_{T\&D}$

η_{m}

η_{p}

A)ELECTRIC MOTOR



η_{cm} 90 %

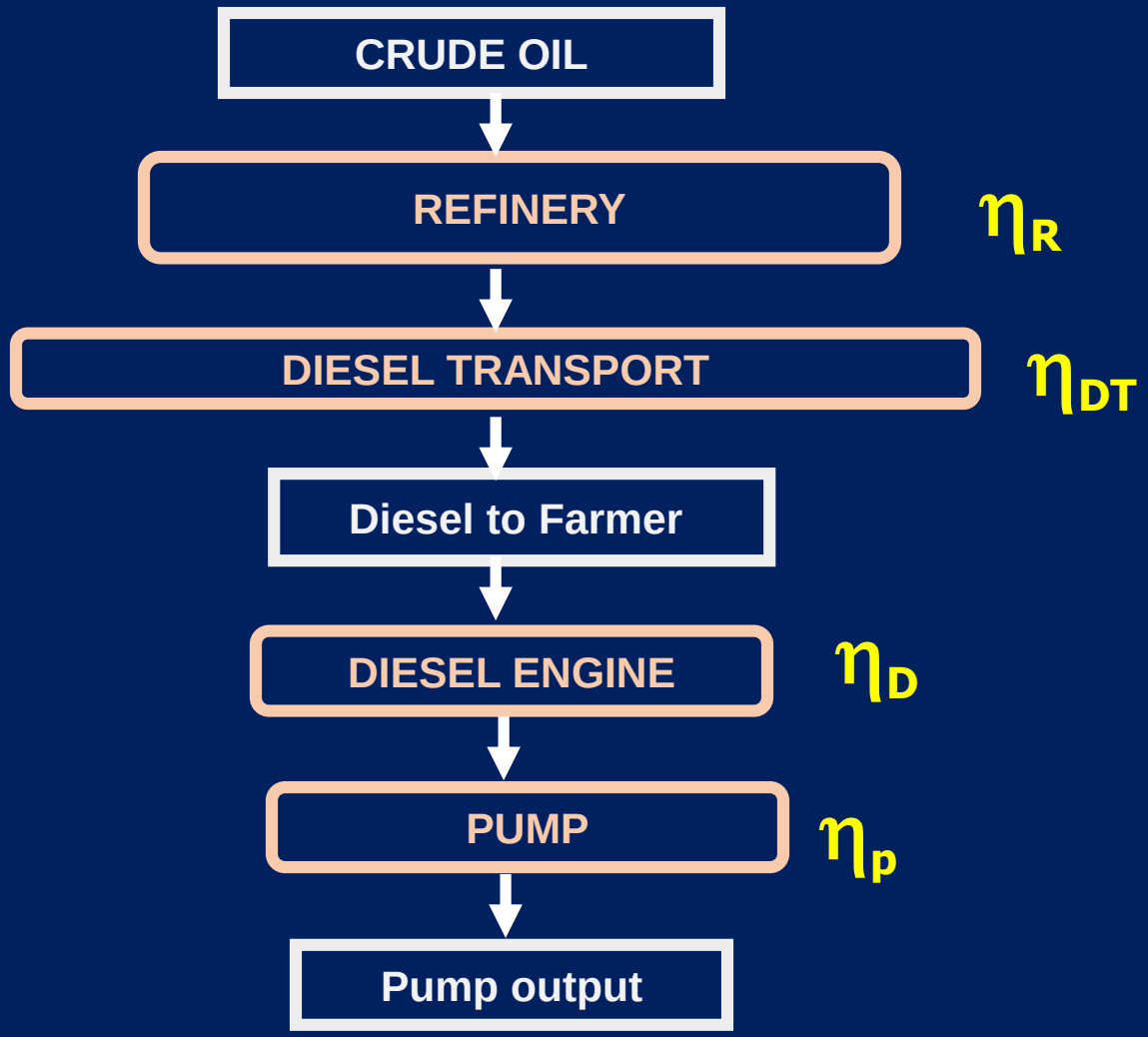
η_{pp} 30 %

$\eta_{T\&D}$ 78 %

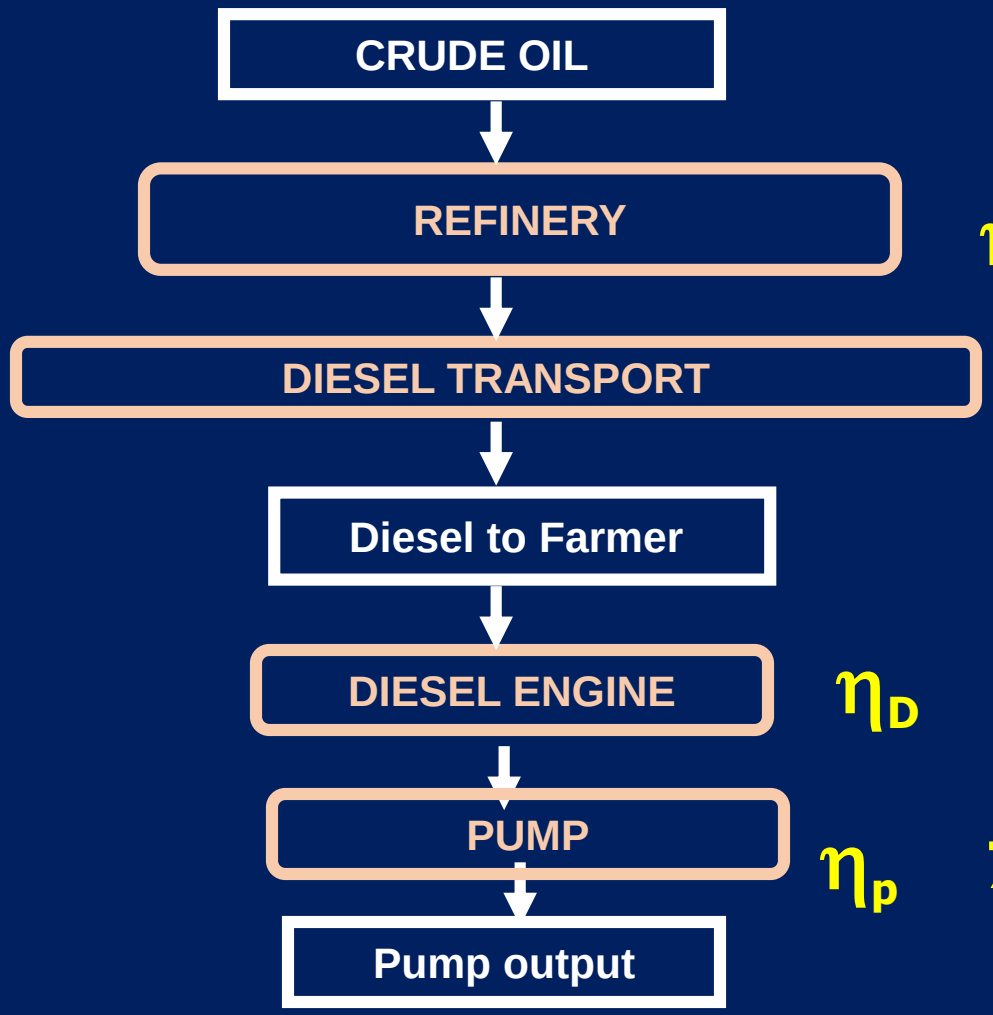
η_{m} 88 %

η_{p} 75 %

B) DIESEL ENGINE



B) DIESEL ENGINE



η_R 92 %

η_{DT} 95 %

η_D 40 %

η_p 75 %

Comparison of Options

- Motor-Pump
- $\eta = \eta_{cm}\eta_{pp}\eta_{T\&D}\eta_m\,\eta_p$
  $\eta = 0.9*0.3*0.78*0.88*0.75$ $\eta = 0.139$ **(13.9%)**
- Electricity bought=
  $3*10^6/(3600*0.75*0.88)$
  $=1263$ kWh

- Diesel Engine-Pump
- $\eta = \eta_R\eta_{DT}\eta_{DT}\eta_D\,\eta_p$
  $\eta = 0.92*0.95*0.40*0.75$
  $\eta = 0.262$ **(26.2%)**
- Diesel Input =
  $3/(0.75*0.4) = 10$ GJ =
  $10*10^6/(9700*4.18*0.85)$
  $=290$ litres

Comparison of Options

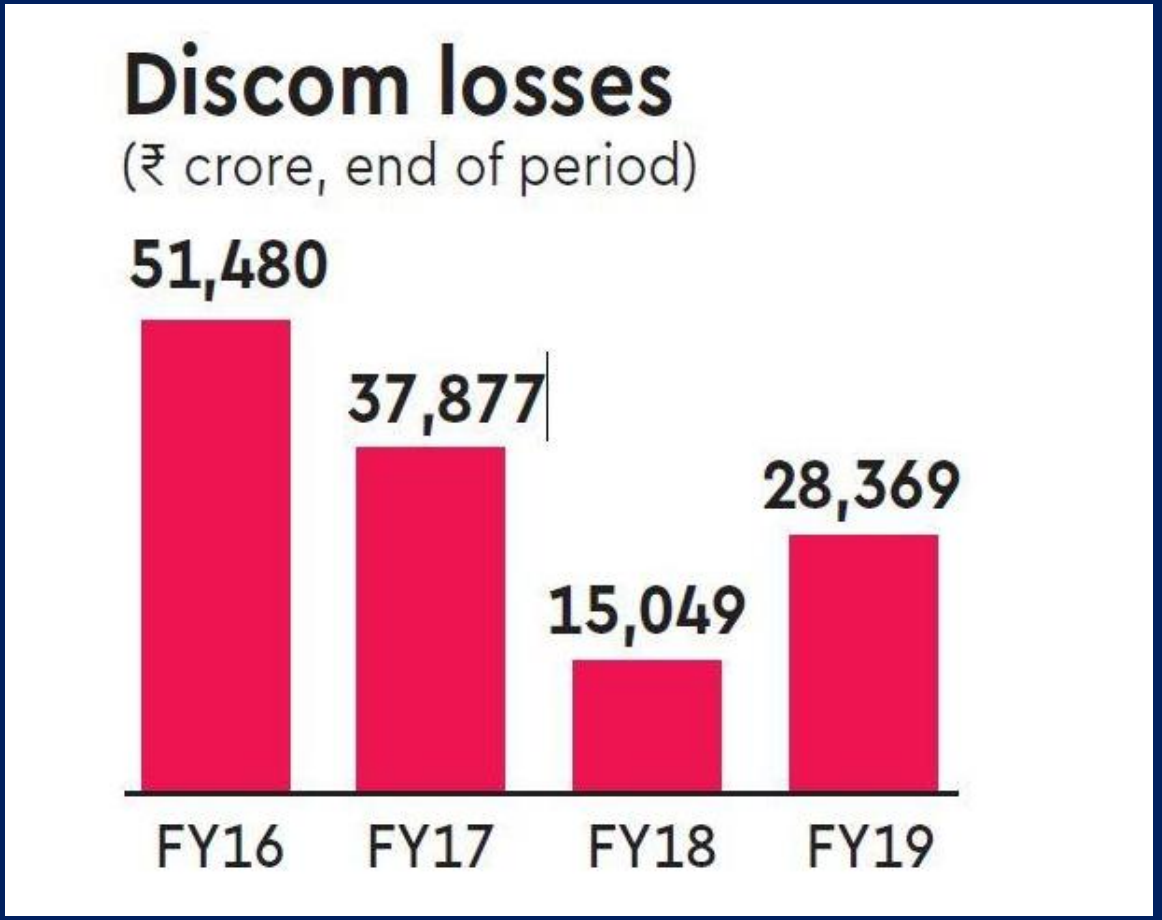
- Motor-Pump
- Energy cost Rs 3789
  (@Rs 3/kWh)
- Capital Cost Rs 12000
- Power Cuts
- 1300 kg of coal
- Coal relatively abundant

- Diesel Engine-Pump
- Energy cost Rs 14509
  (@Rs 50/litre)
- Capital Cost Rs 24000
- Uninterrupted
- 300 kg of crude oil
- Refinery Mix

Gasifier Option

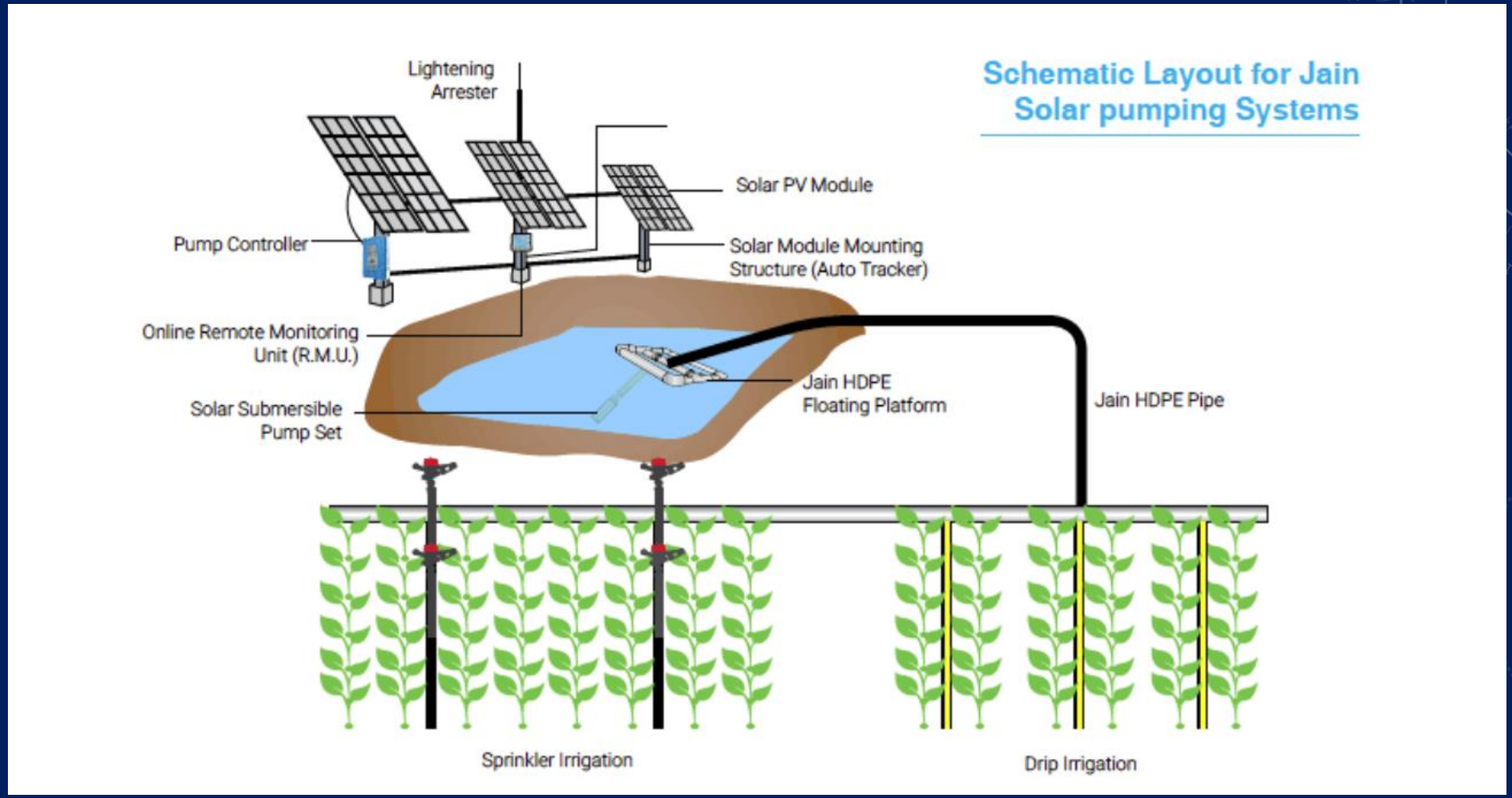
- 75% Diesel replacement
- 70% gasifier efficiency
- 75 litres diesel, 754 kg biomass
- Biomass price Rs 2/kg Rs 3830
- Capital Cost Rs 48000
- Operation & Maintenance

Distribution Company losses



https://www.financialexpress.com/economy/uday-scheme-discoms-losses-rise-89-in-fy19/1660106/

Solar PV pumping



https://www.jains.com/Solar/Solar%20Pumping%20Systems.htm

Solar PV pumps

Sample specifications

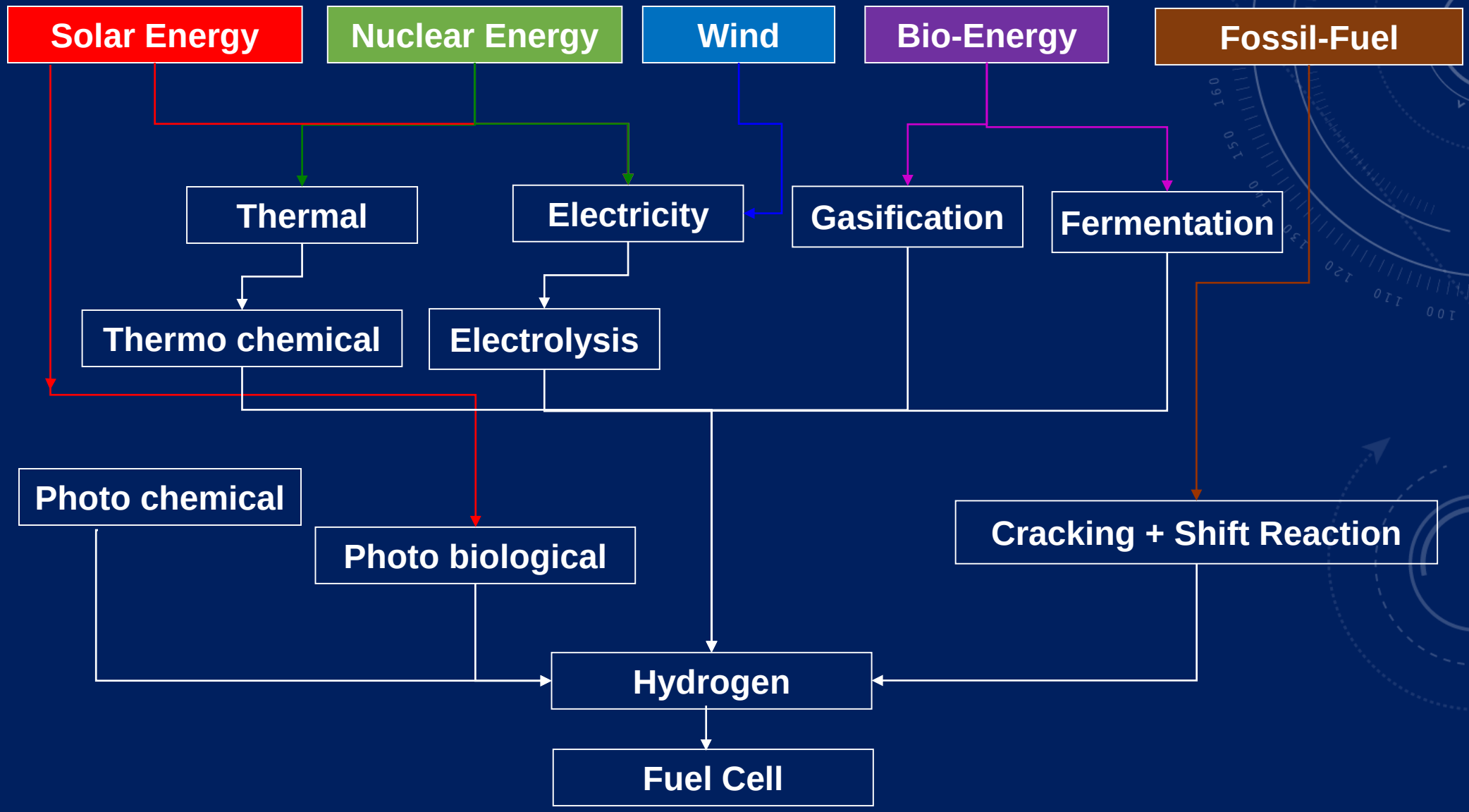
Table 4: MNRE Indicative Technical Specifications for Surface Pumps and Submersible Pumps

Description	Model 1	Model 2	Model 3	Model 4
Centrifugal DC monoblock				
Solar PV Array	900 Wp	1,800 Wp	2,700 Wp	n/a
Motor Capacity	1 HP	2 HP	3 HP	n/a
Max. TDH*	10 mtrs.	15 mtrs.	25 mtrs.	n/a
Submersible motor with electronic controller				
Solar PV Array	1,200 Wp	1,800 Wp	3,000 Wp	4,800 Wp
Motor Capacity	1 HP	1 HP / 2 HP	3 HP	4.6 HP
Max. TDH*	70 mtrs.	70 mtrs.	120 mtrs.	160 mtrs.

**Max. TDH – Maximum Total Dynamic Head*

https://tuewas-asia.org/wp-content/uploads/2017/05/30-Solar-Water-Pumping-for-Irrigation-Opportunities-in-Bihar-India.pdf

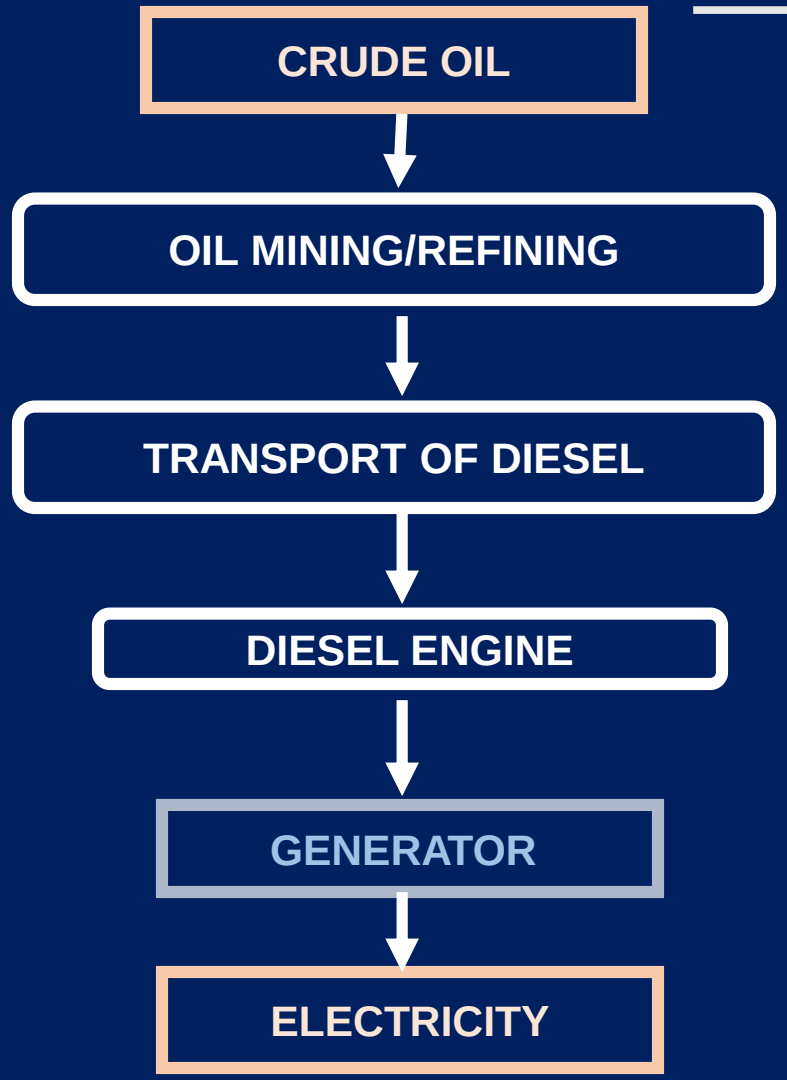
Hydrogen pathways



Applications

- A-Distributed Power Generation – Rating 100 kW
- B- Vehicle – 4 wheeler passenger car (Maruti 800)
- Base Case A1- Diesel Engine – Generator (fuel diesel), A2 Gas Engine – Generator (fuel natural gas)
- Base Case B1 - IC Engine - petrol , B2- CNG engine

A1)DIESEL ENGINE



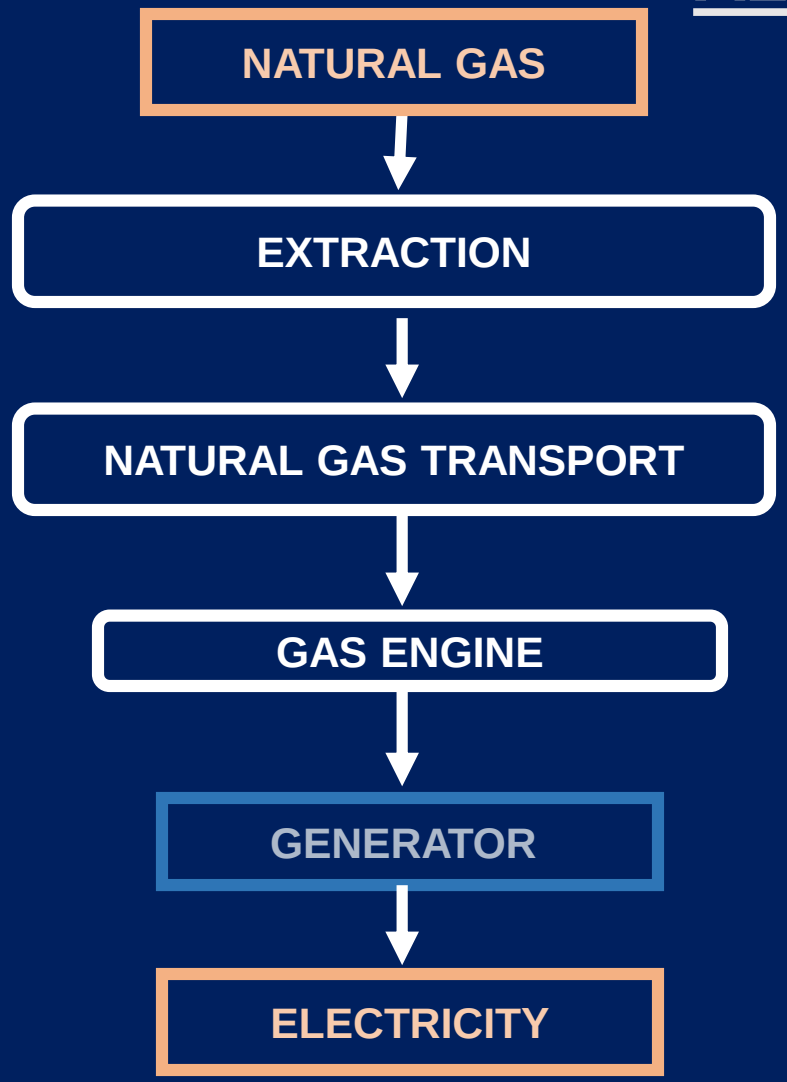
η_{OM} 95 %

η_{TD} 97%

η_{DE} 40 %

η_{GEN} 95 %

A2) GAS ENGINE



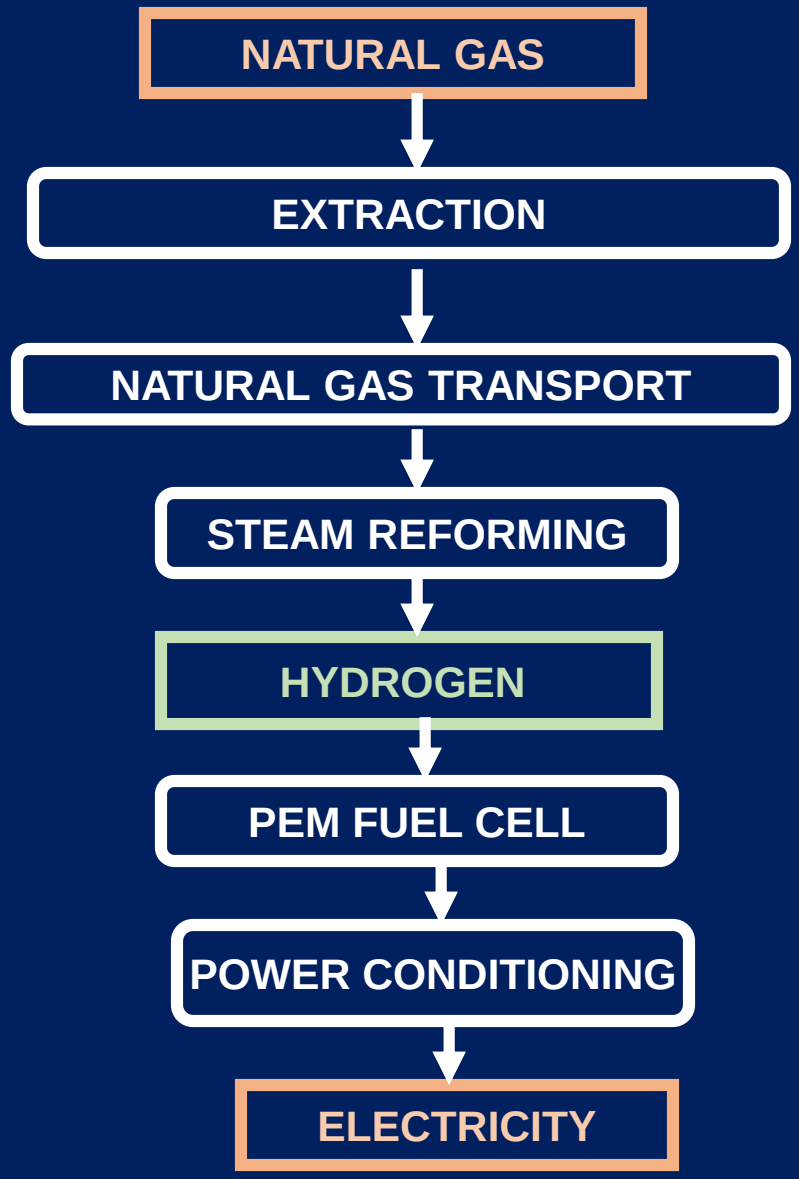
η_{OM} 95 %

η_{TD} 97%

η_{DE} 42 %

η_{GEN} 95 %

FUEL CELL (NG)



η_R 95 %

η_{GT} 97 %

η_{REF} 85 %

η_{FC} 40 % (50%)

η_{PC} 95 %

Distributed Generation

- A1 Overall efficiency 35%

  0.246 kg of crude /kWh of electricity
- A2 Overall efficiency 37%

  0.25 kg of Natural gas/kWh of electricity

Fuel cell Overall efficiency 30% 0.307 kg of Natural gas/kWh of electricity

(37% like A2 FC eff 50%)

Carbon Emissions

- A1 – Crude oil (86% Carbon)
  0.211 kg Carbon/kWh
- A2- Natural gas (75% Carbon)
  0.187 kg Carbon/kWh

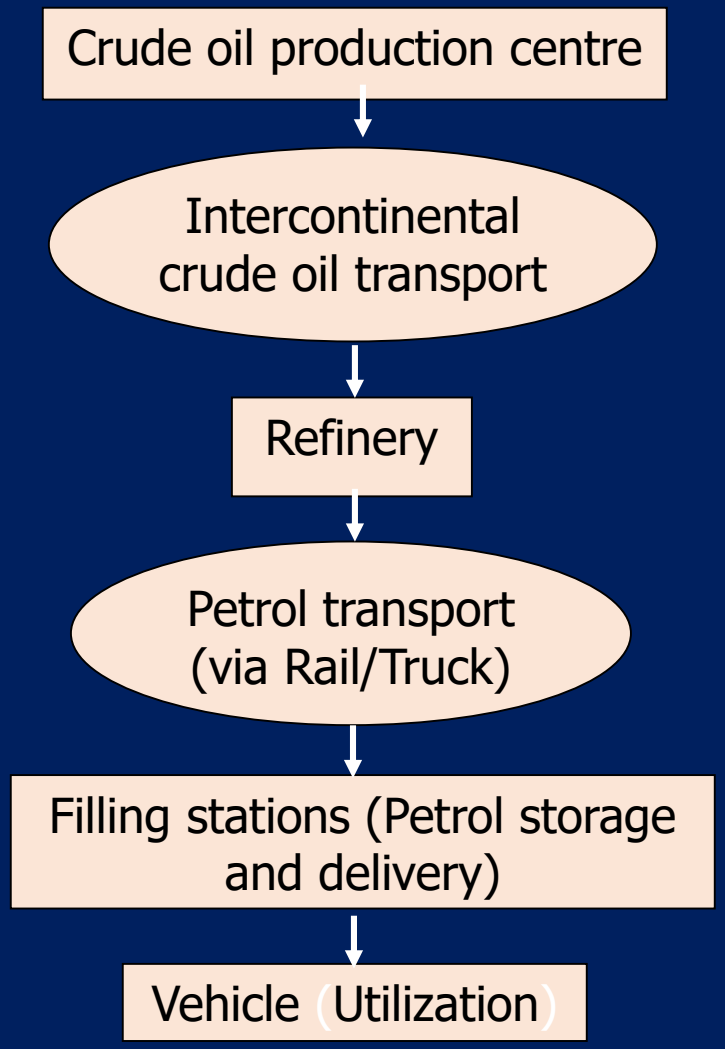
Fuel cell (18 kg of Carbon / 1 GJ of Hydrogen energy – SMR)

FC eff 0.4 - 0.171 kg Carbon/kWh

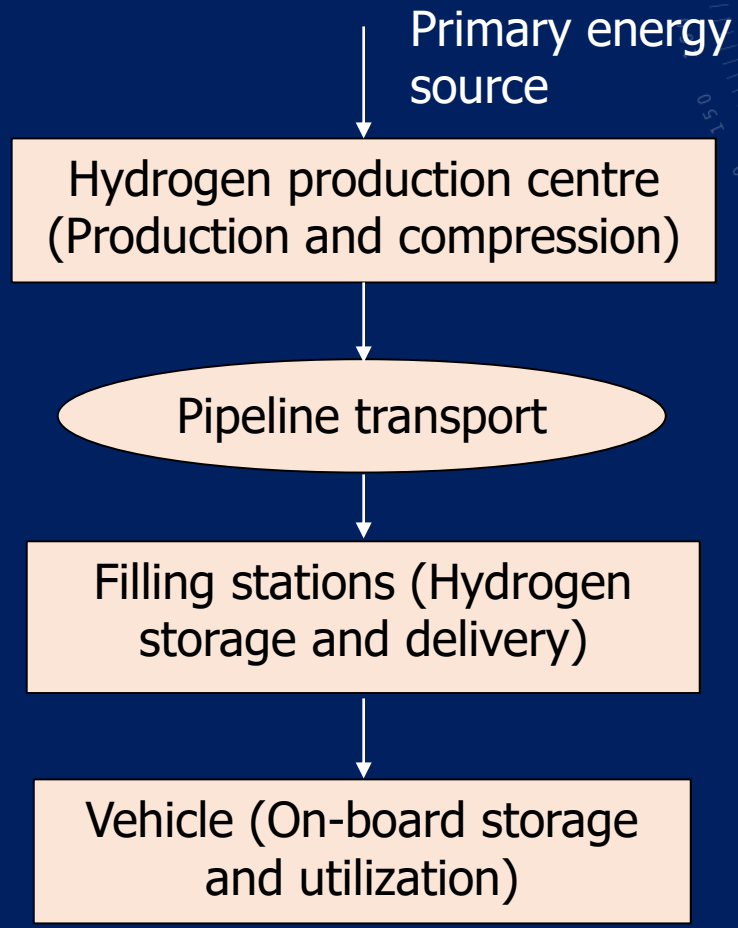
0.5- 0.136 kg Carbon/kWh

Fuel chains

Fossil fuel chain



Hydrogen fuel chain



Base case Fossil fuel based fuel chain

- Small-size passenger car (Maruti 800) manufactured by Maruti Udyog Limited
  - Petrol fuelled,
  - 37 bhp (27 kW) IC engine

50% share in Indian passenger vehicle-market

560,000 units sold 2005-6

Vehicle Application

- Weight (excl engine +tank) 550 kg
- Passengers (max) 350 kg

Maruti

CR 0.01

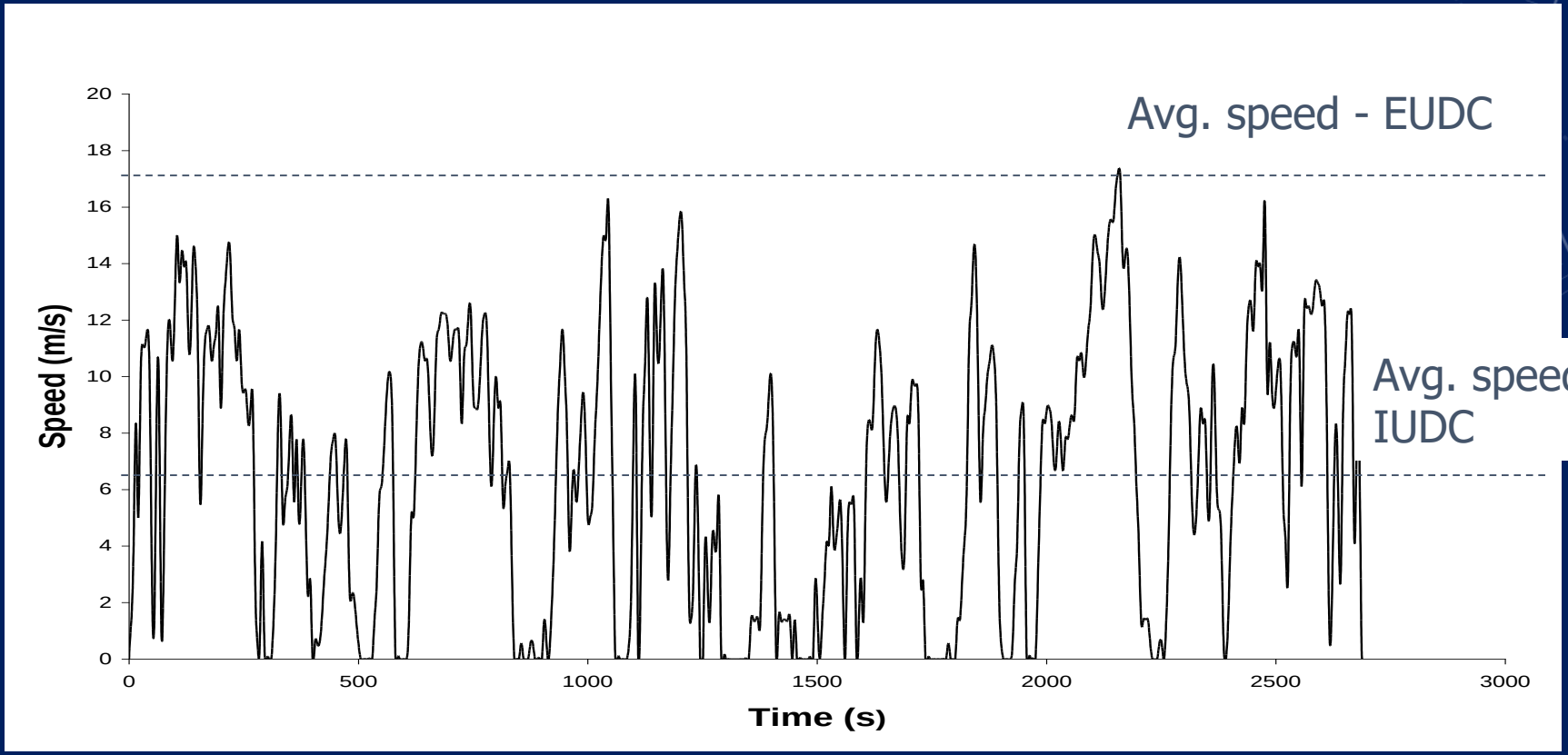
CD 0.4

$2m^2$ front area

100 km travel /day

	Tank	Engine
Petrol	40 kg	60 kg
CNG	140 kg	60 kg
FC	130 kg	15 M +15 FC kg

Indian urban drive cycle



Indian urban drive cycle **:-**

Low average speed (23.4 km/h) and rapid accelerations (1.73 to -2.1 m/s^2)

European urban drive cycle **:-**

Average speed (62.4 km/h) and accelerations from 0.83 to -1.4 m/s^2

Power required at wheels

- Three forces acts on the vehicle (Assumption:- vehicle is running on a straight road with a zero gradient). These are
  - Aerodynamic drag $\{F_{Drag}(t)\} = 0.5\rho A v(t)^2 C_d$
  - Frictional resistance $\{F_{Friction}(t)\} = mgC_r$
  - Inertial force $\{F_{Inertia}(t)\} = mf$ $\{f=dv(t)/dt\}$
- $F_{Total}(t)=F_{Drag}(t)+F_{Friction}(t)+F_{Inertia}(t)$
- $P_{Wheel}(t)=F_{Total}(t)\times v(t)$

Data used for base case vehicle

Parameter	*Value*
Air density (kg/m^3)	1.2
Coefficient of drag resistance	0.4
Coefficient of rolling resistance	0.01
Cargo weight (kg)	250
Frontal area (m^2)	2
Transmission efficiency	0.7
Transmission weight (kg)	114
IC engine weight (kg)	90
Fuel tank weight (kg)	40
Fuel capacity (kg)	24
Vehicle body weight (kg)	406
Total weight (kg)	900

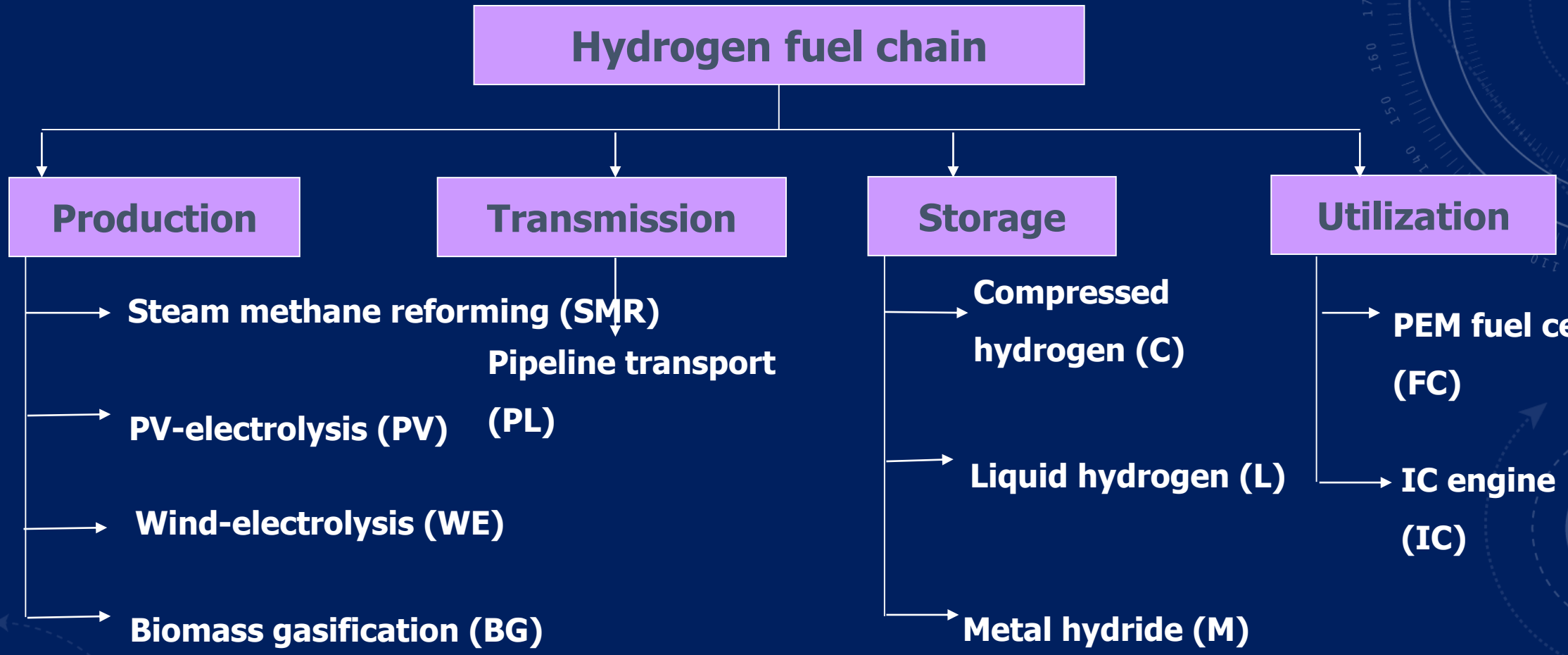
Result for base case vehicle

Parameter	*Value*
Driving range (km)	434
Cost (Rs/km)	2.8 (0.34)
Non-renewable energy use during operation (MJ/km)	2.6
GHG emissions (g/km)	180

Driving range of hydrogen vehicles should be at least half (~217 kms) for their public acceptance.

- Average daily travel Indian urban <100 kms.
- Vehicle to run for 2-3 days.

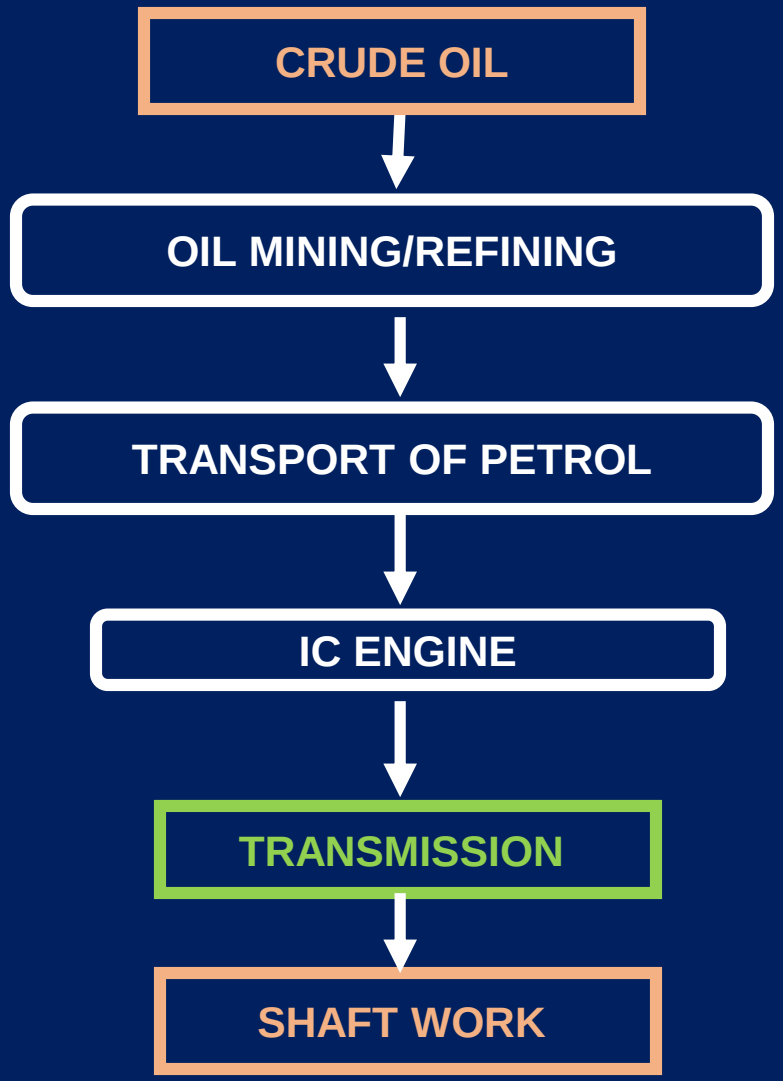
Hydrogen fuel chain – Options considered



Hydrogen production – Steam Methane Reforming (SMR)

- Feedstock - Natural Gas
- SMR: $CH_4 + 2H_2O \rightarrow 4H_2 + CO_2$
- Life of plant 20 years
- Existing NG price Rs 8/Nm^3,
- Price of Hydrogen Rs 48/ kg 4.3 Rs/Nm^3 or 400 Rs/GJ

B1) PETROL ENGINE



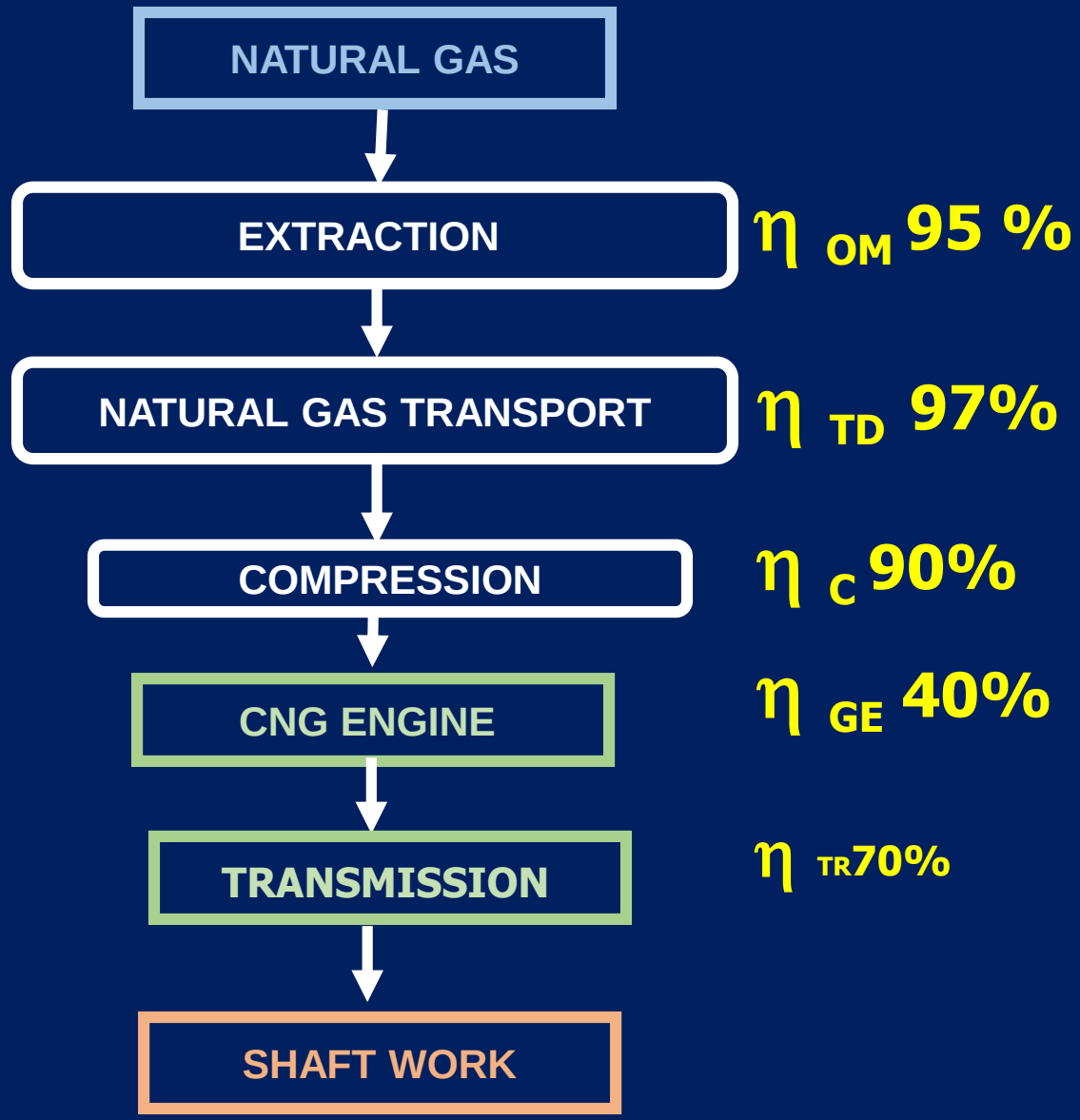
η_{OM} 95 %

η_{TP} 97%

η_{PE} 30 %

η_{TRANS} 70 %

B2) GAS ENGINE



η_{OM} 95 %

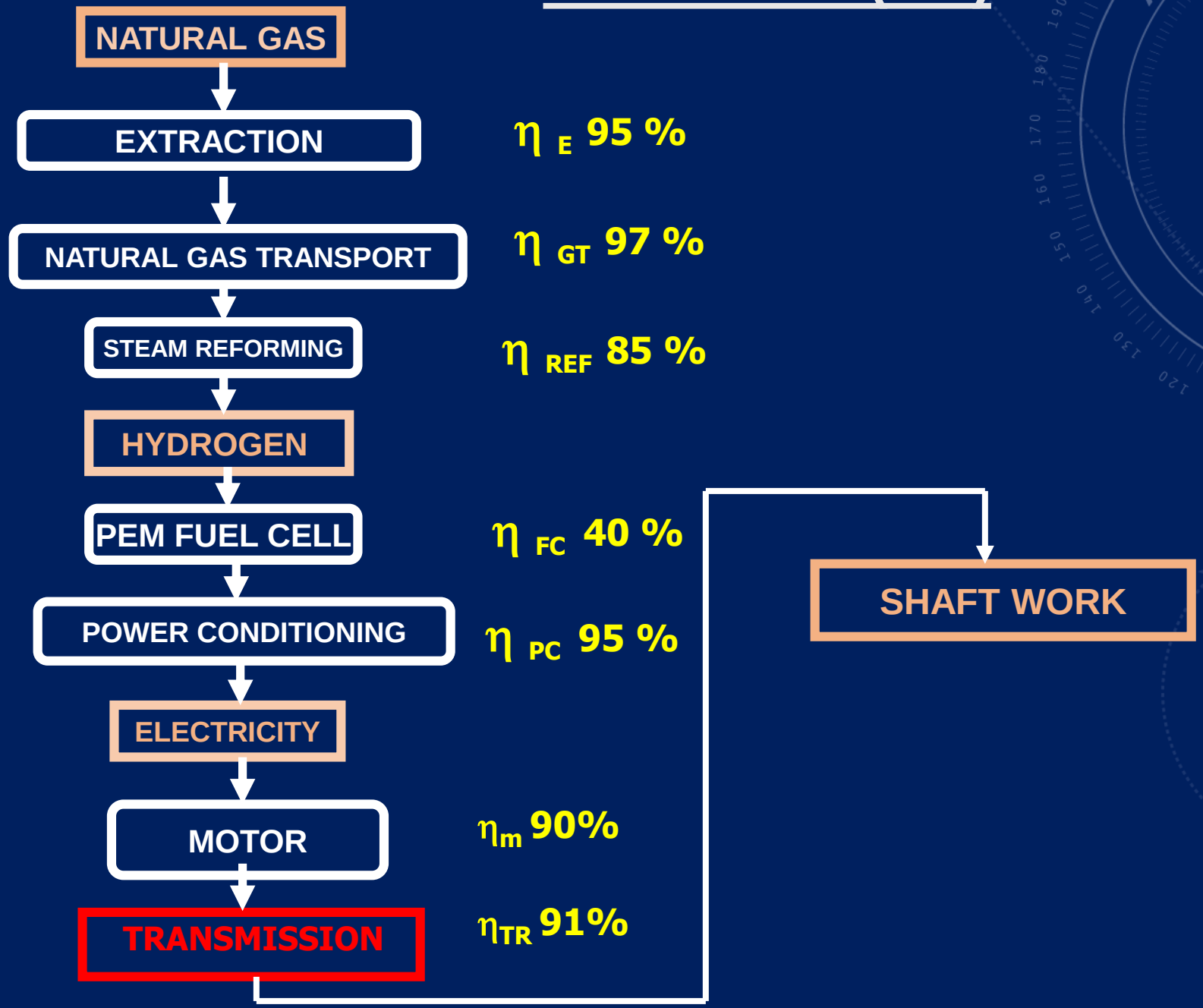
η_{TD} 97%

η_{C} 90%

η_{GE} 40%

η_{TR} 70%

FUEL CELL (NG)


NATURAL GAS
EXTRACTION
NATURAL GAS TRANSPORT
STEAM REFORMING
HYDROGEN
PEM FUEL CELL
POWER CONDITIONING
ELECTRICITY
MOTOR
TRANSMISSION
η E 95 %
η GT 97 %
η REF 85 %
η FC 40 %
η PC 95 %
ηm 90%
ηTR 91%
SHAFT WORK

Vehicle Comparison

- B1 Overall efficiency 19.4%

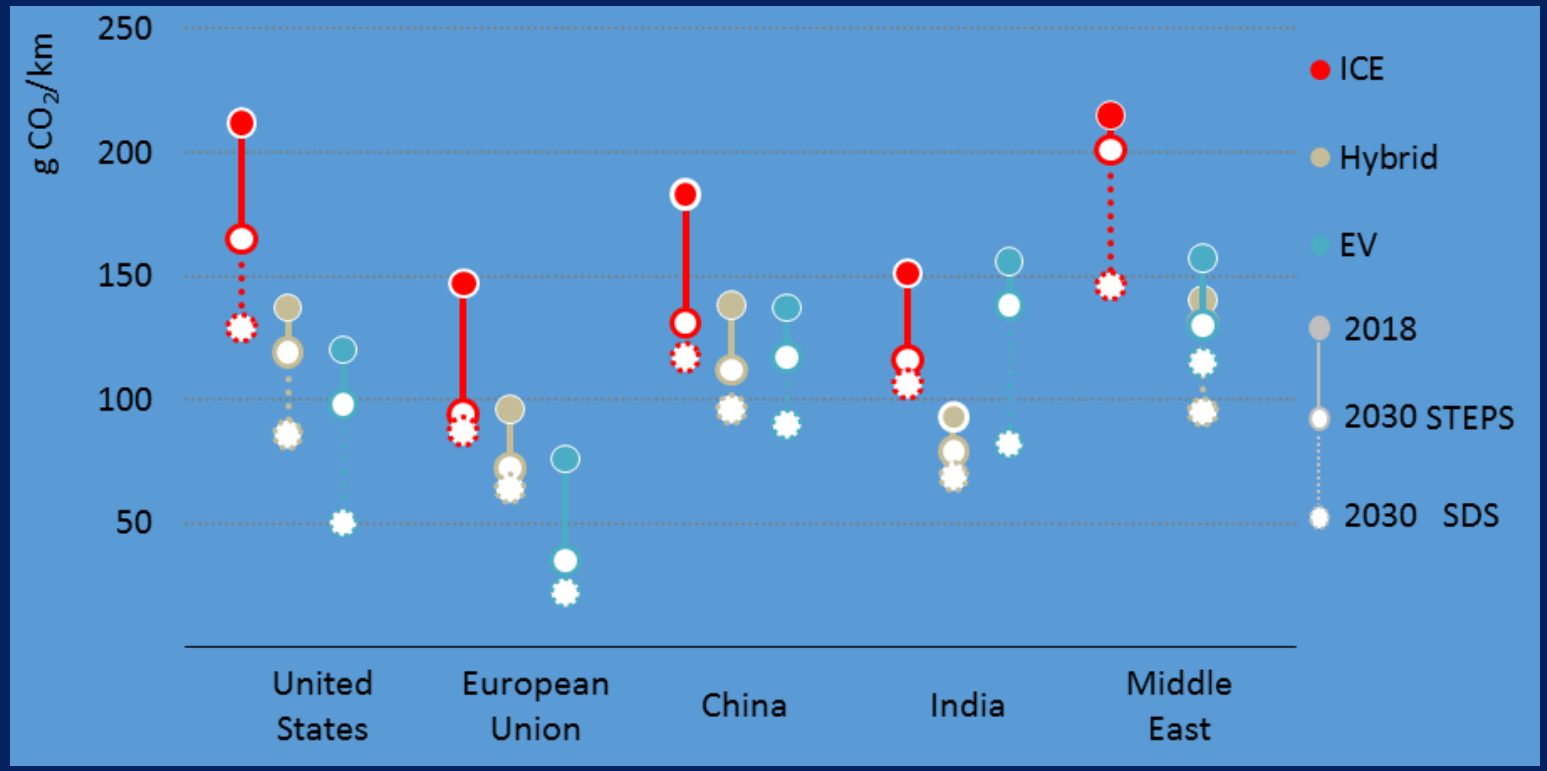
  3.31 kg of crude /100 km of travel
- B2 Overall efficiency 23.2%

  3.0 kg of Natural gas/ 100 km of travel

Fuel cell Overall efficiency 24.3%

2.82 kg of Natural gas/ 100 km of travel

Carbon emissions of different car powertrains by region



The relative carbon footprint of ICE versus electric cars strongly depends on the power sector mix

Source: World Energy Outlook 2019 IEA
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