Alternative District Heating Fuel: Pyrolysis oil

ETM 531/631: Technology Assessment and Acquisition

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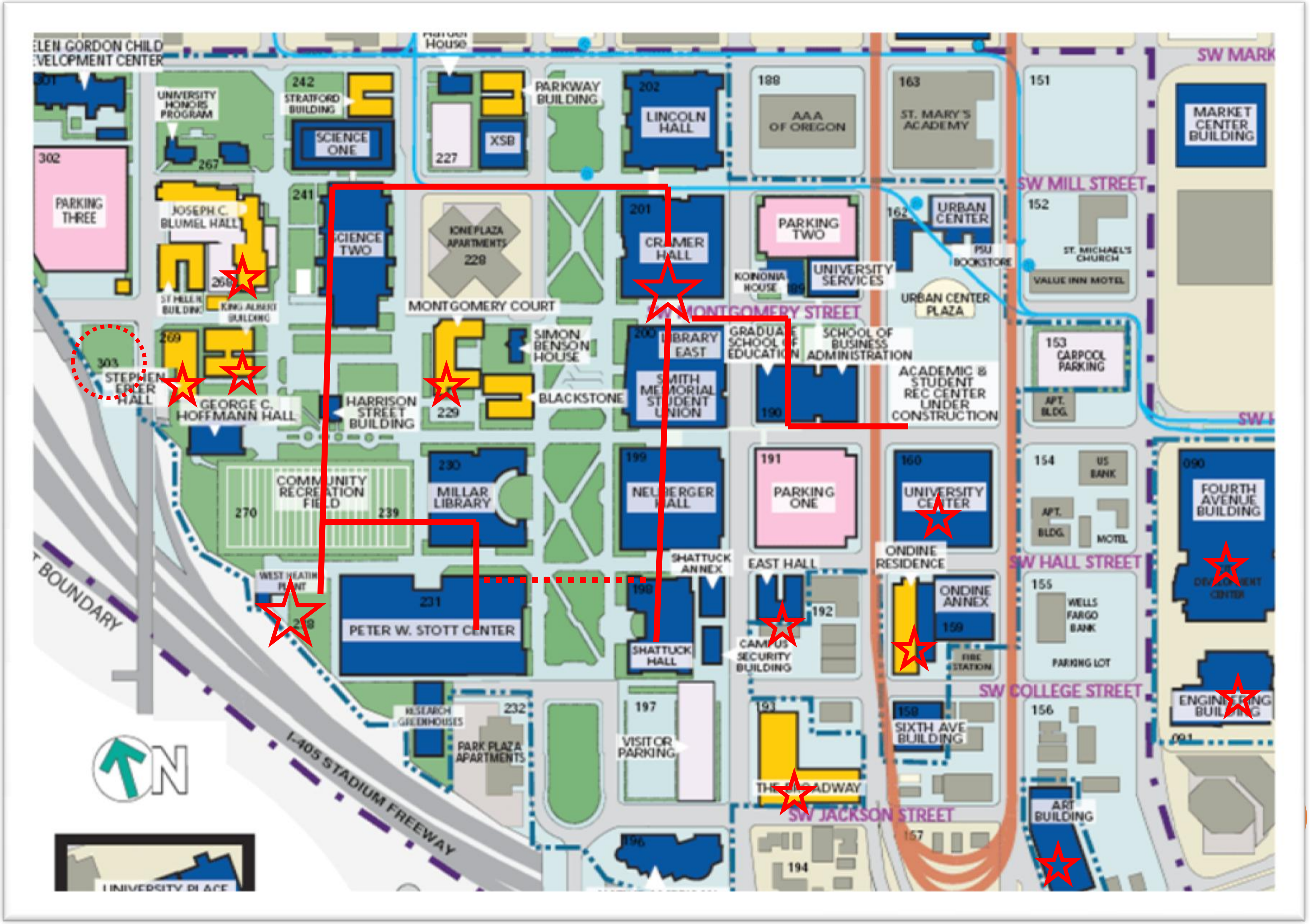
CURRENT STATUS

- PSU campus consists of about 60 buildings on 50 acres.
- PSU heating system mainly relies on two heating plants with 7 natural gas fired boilers.
- A 2.5 MW diesel fired turbine was installed in the University's newest building at 1900 SW Fourth Street in 2006.
- The campus also has another 7 small natural gas fired boilers that serve individual buildings.
- PSU heating system is required 8 months per year.
- Only two boilers at West Plant provide domestic hot water for the campus during the summer.
- The approximate operating time is 14 hrs/day, 6 days/wk.

PSU CAMPUS MAP



Problem Statements

- PSU is not a major source of criteria pollutant emissions.
- PSU is not a major source of hazardous air pollutants.
- The facility was inspected in May 2008 and found to be in compliance with Air Contaminant Discharge Permit conditions.

If PSU is considering to use an alternative fuel for its district heating system, what fuel source would you recommend?

Gap Analysis

Gap Analysis	Requirements	Capabilities	Gaps
Technical	- Minimal environmental impacts - Competitive fuel cost - Easily switching from current fuel to alternative fuel	- Low air particle emission -Scalable reactor -Level of efficiency	- Technologies should be proven - Need to reduce cost of operation - Reduce environmental impact
Organizational	-Green campus - Air contaminate approved by Department of Environmental Quality (DEQ) - Competitive fuel cost - Competitive maintenance cost	- Abundance of renewable resources that head to landfills each day -Waste management potential - Ability to store back up fuel on campus if needed	- Need to prove that candidate technologies will not violate pollution standard - Demonstrate cost effectiveness to PSU Facilities and Planning
Personal	- Safety - Acceptance	- Operators skills - Sustainability	- Proof of safety - Acceptance of Operators

Candidate Technologies

- Natural Gas

- Marine Diesel Oil

- Pyrolysis Oil

RedOx

Natural Gas

- Natural gas is a highly combustible odorless and colorless hydrocarbon gas largely composed of methane.
- Natural gas is a fossil fuel that is non-renewable.
- Natural gas is commercially produced from oil fields and natural gas fields.
- Before natural gas can be used as a fuel, it must undergo extensive processing to remove almost all materials other than methane.
- It is an important fuel source, a major feedstock for fertilizers, and a potent greenhouse gas.
- Natural gas is often informally referred to as simply gas, especially when compared to other energy sources such as oil or coal.
- The most current estimates put the world reserves at roughly six thousand trillion (6 × 1015 cu ft)13 given current rate of use it equates to between 60 and 65 years worth of supply.

Marine Diesel Oil

- A mix of the heaviest part of distillate fuels and residual oil.
- A major fuel oil for large steam boilers and very large compression ignition engines, such as ocean-going ships.
- The main drawback to marine diesel oil is its high initial viscosity that it has to be heated with a special heating system before use.
- Since it requires heating before use, it cannot be used in road vehicles or boats.
- It contains relatively high amounts of pollutants, particularly sulfur.
- Its undesirable properties make it cheap
- In 1973, marine diesel oil produced 16.8% of the electricity in the United States. By 1983, it had fallen to 6.2%, and as of 2005, electricity production from all forms of petroleum, including diesel and residual fuel, is only 3% of total production.
- The decline is the result of price competition with natural gas and environmental restrictions on emissions (produces much darker smoke than natural gas)

Pyrolysis Oil

- Pyrolysis corresponds to the thermochemical conversion / rapid thermal decomposition of waste and biomass (wide variety of feedstocks can be used) occurring in the absence of oxygen.
- Biomass pyrolysis results in the production of three products: gas, pyrolysis oil and charcoal.
- Pyrolysis (bio-oil) from flash pyrolysis is a low viscosity, dark-brown fluid with up to 15 to 20% water.
- Prolysis oil is rich in carbon and can be refined in ways similar to crude petroleum.
- Conversion to 75 wt-% bio-oil translates to energy efficiency of 70%
- Pyrolysis quality issues:–Moisture content–Particulate content–Sulfur and nitrogen content–Stability
- There are several kinds of fast pyrolysis reactors.
- Production is unlimited.

Natural Gas

- Cost
  - Implementation: None (currently in use)
  - Price per unit (MBTU): $16.24 (Nov 13, 2009)
- Environment
  - Emission: Low
- Availability (Short/Long term)
  - High/Low (approx. 30 years)
- Safety
  - Flammable Limits in Air 5-15%
  - Biodegradability (N/A- gas)
- Sustainability: Limited

Marine Diesel Oil

- Cost
  - Implementation: None
  - Price per unit (MBTU): $21.08 (Nov 13, 2009)
- Environment
  - Emission: High (NO_x)
- Availability (Short/Long term)
  - -High/Low (approx. 30 years)
- Safety
  - Flammable Limits in Air 0.5-5%
  - Biodegradability (28 day period, 24-36%)
- Sustainability: Limited

Pyrolysis Oil

- Cost
  - Implementation:
    - Upgrade the storage
    - Boiler adjusting
  - Price per unit (MBTU): $17.56 (Approximately)
- Environment
  - Emission: High (Particles)
  - Carbon neutral
  - Carbon Sequestration
- Availability (Short/Long)
  - Low/High
  - Potentially unlimited
- Safety
  - Flammable Limits in Air 0.9-5.9%
  - Biodegradability (28 day period, 41-50%)
- Sustainability: Potentially High

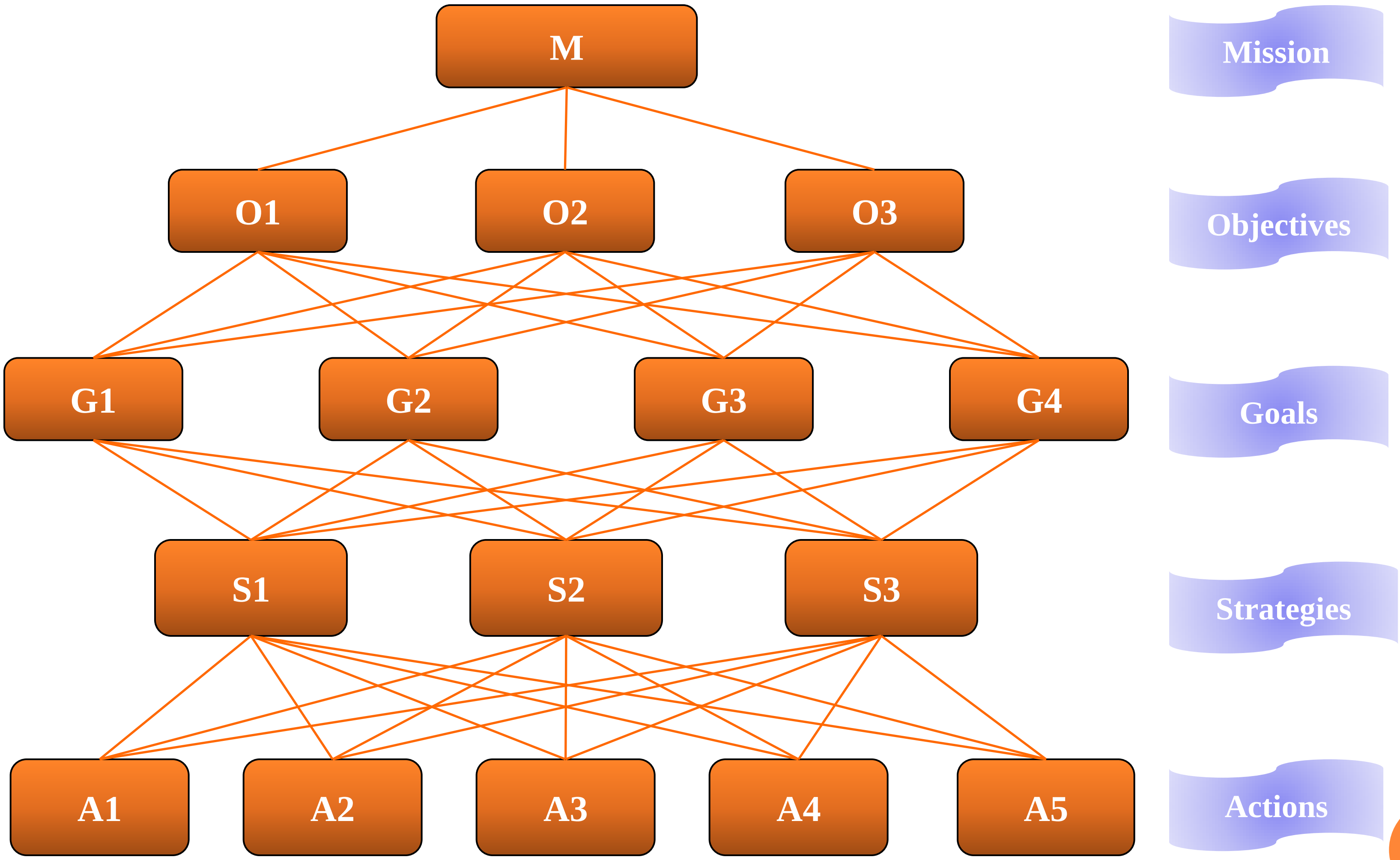
Candidate Technologies Matrix

Needs / Candidate Technologies	Implementation Costs ($)	Price per unit (MBTU)	Environmental Impact	Availability Short term/ Long term	Safety F/Bio	Sustainability
Natural Gas	None	$16.24	Low	High/ Low	High/ High	Limited
Marine Diesel Oil	None	$21.08	High	High/ Low	Low/ Low	Limited
Pyrolysis Oil	- Upgrade the storage - Adjust boiler	$17.56	High / Carbon neutral	Low/ High	Low/ Med	Potentially High

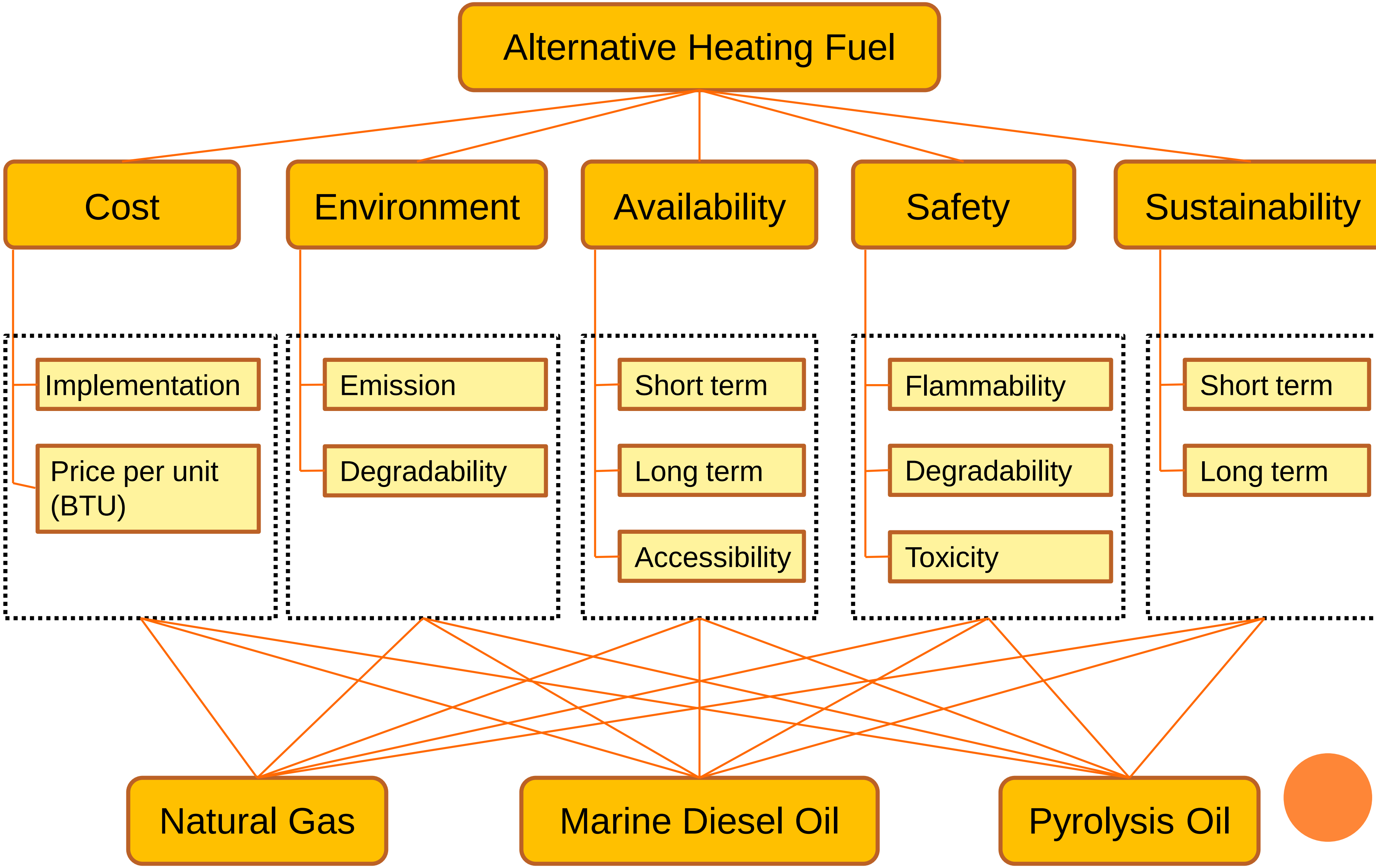
Hierarchical Decision Model

- The hierarchal decision model can be used to construct the decision model to evaluate each fuel technology. We conducted the analytical hierarchy process (AHP) to support technology assessment.
- The significant decision criteria for candidate technologies based on research and interviews.
- The decision criteria are then broken into a set of sub-criteria and each of these sub-criteria contributes as a part of each major criterion's weight
- The final goal will be selecting one of technologies that can overcome the gap as a recommended solution for district heating system

Hierarchical Decision Model



Technology Assessment Model: HDM



Cost

- Implementation
  - Cost of using NG consist of pipelines, pipe insulation, pipe construction, storage tank, and boiler adjustment.
  - Cost of MDO and Bio-Oil consist of pipelines, pipe construction, storage tank, insulation for the tank, fuel warming system, and boiler adjustment.
- Cost (dollars) per Million BTU
  - Different units such as gallons of oil, therms of natural gas, or kilowatt hours (kWh) of electricity
  - Based on the fuel price per unit (dollars), fuel heat content per unit (BTU) and the heating system's efficiency.

Environment

- Emission
  - The products of combustion such as CO_x, NO_x, SO_x, Particulates, and Mercury
  - Green House Gas
  - Acid rain
- Degradability
  - Long term negative affect to environment such as oil spill in soil and water.

Availability

- Short Term
  - The volume of resources available to boiler fuel customers today. Short Term availability refers to the capacity of local distributors to meet the needs of PSU's boilers.
- Long Term
  - The total volume of resources, including the estimated duration of time that these resources will be available. Special consideration should be given to fuel resources that can be defined as having a limited known quantity.
- Accessibility
  - The ability and ease with which the distributor can meet the demands of PSU. Consider the rapidity and convenience of fuel delivery, as well as local storage versus distribution and feed systems.

Safety

- Flammability
  - The overall mixture of oxygen to material that can be ignited. A larger low to high concentration area should be considered more flammable. Special consideration should be given to mixtures less likely to combust at standard PSU temperatures.
- Degradability
  - Most materials biodegrade over time. This is a measurement of the amount of time that a given substance will bio-degrade within a standard period. Fuel substances with high degradability are vegetable oil, substances with low degradability are fossil oils.
- Toxicity
  - Fuels may be more or less likely to burn skin or irritate eyes. Consider toxicity in terms of a possible fuel leak into the environment, or fuel-handler exposure.

Sustainability

- Short Term
  - Sustainability is the degree to which system operation may depletes natural resources. In the case of boiler fuels, fossil fuels can not be recreated in a timely fashion, and therefore would rank low.
- Long Term
  - Boiler fuels with higher sustainability would be bio-mass generated fuels such as Pyrolysis Oil generated from organic and renewable feedstock.
  - In the case of RedOx reactor generated Pyrolysis oil, the feedstock would be municipal waste. Due to the heterogeneous nature of the feedstock, the ease of sustainability is increased.

Pairwise Comparison

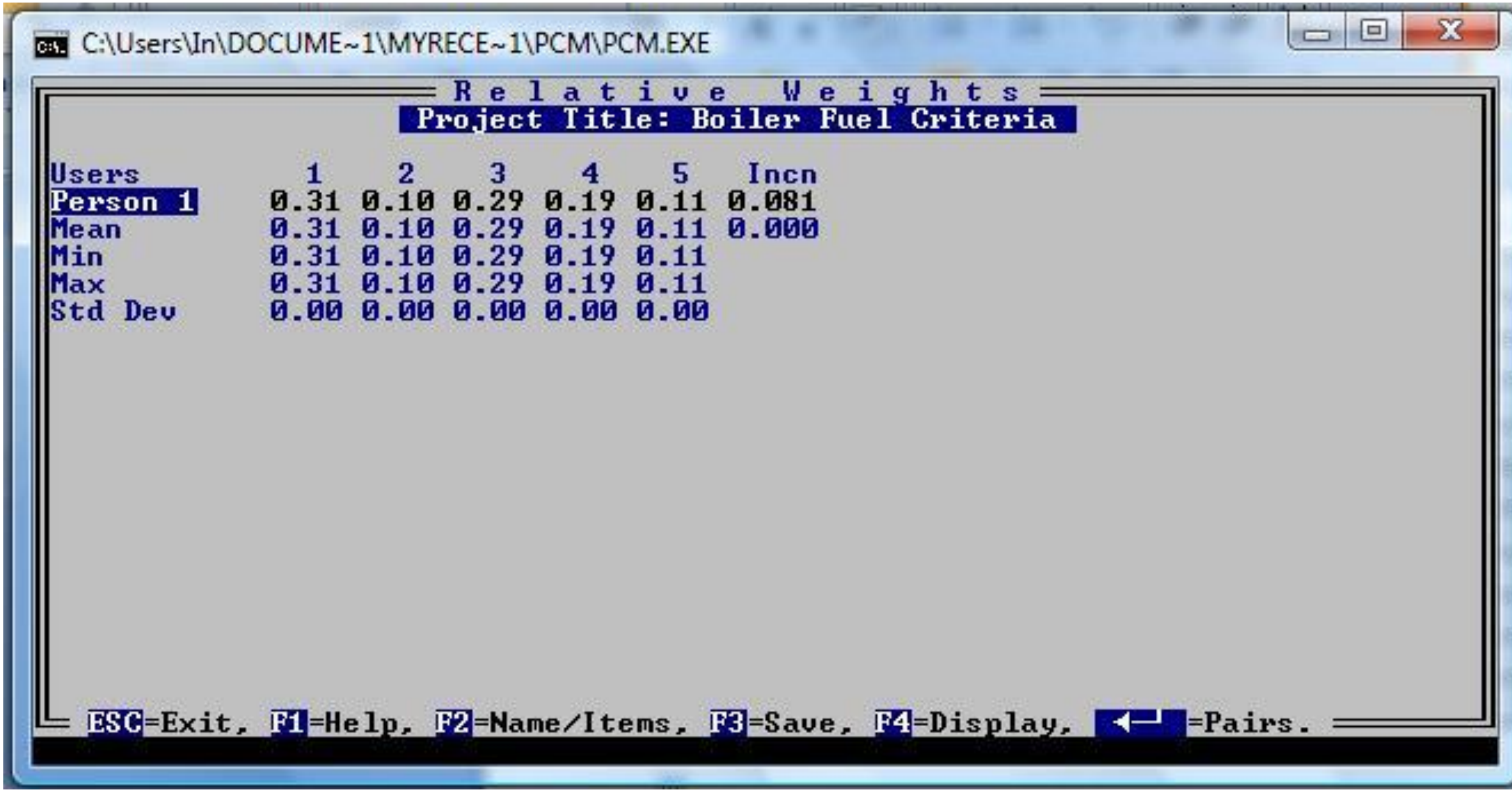
PSU Boiler Fuel Oil, Pairwise Comparison for HDM

Participant's Name: ____________________ Affiliation: ____________________

	Criterion	Weight (%)	Weight (%)	Criterion
1.	Cost	70	30	Environment
2.	Environment	40	60	Safety
3.	Cost	65	35	Safety
4.	Environment	10	90	Availability
5.	Availability	50	50	Sustainability
6.	Cost	80	20	Sustainability
7.	Environment	60	40	Sustainability
8.	Availability	60	40	Safety
9.	Safety	70	30	Sustainability
10.	Cost	50	50	Availability

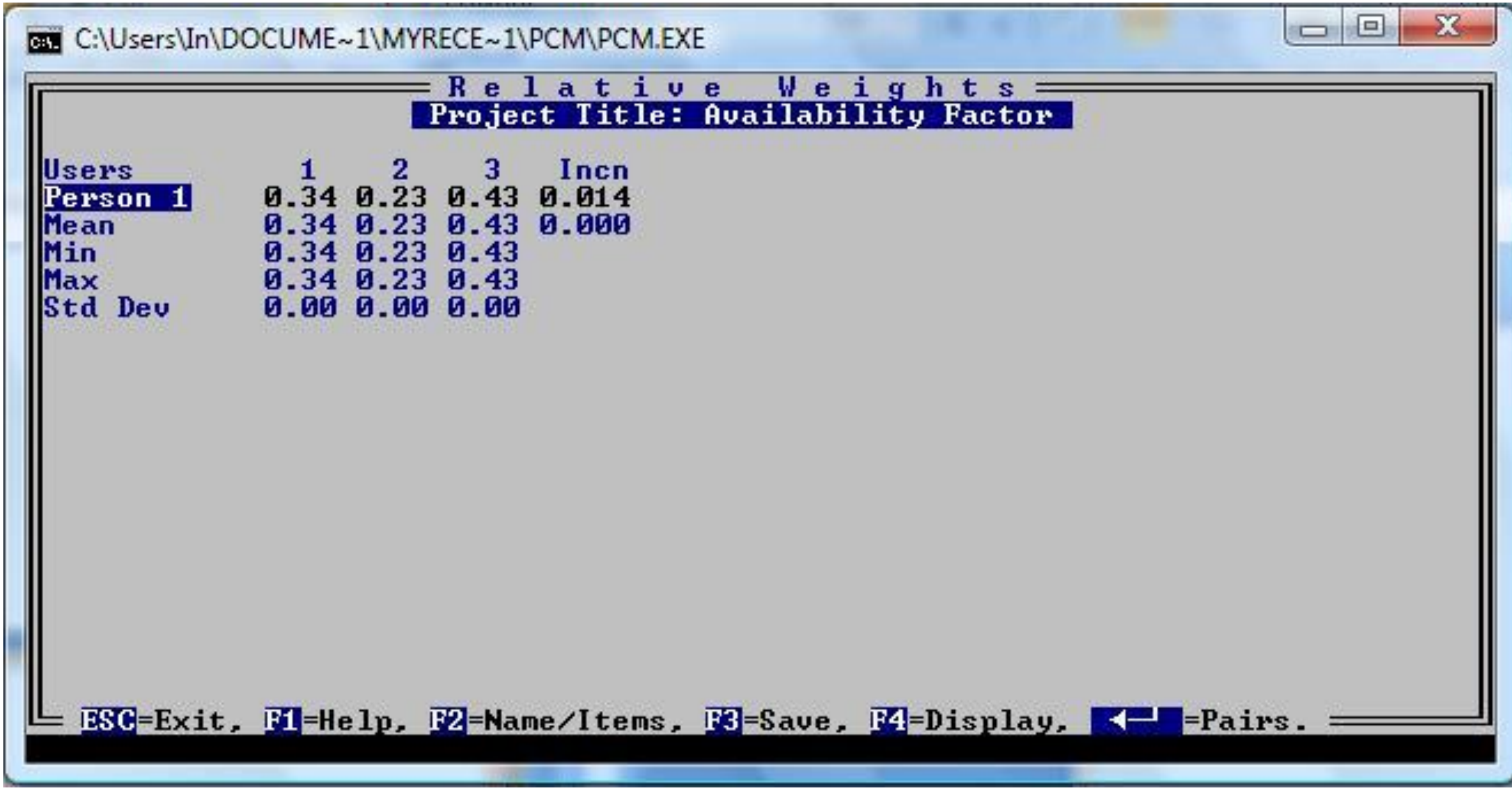
1.	Factor	Weight (%)	Weight (%)	Factor
2.	Implementation	30	70	Price per Unit (Btu)
3.	Emissions	80	20	Degradability (Environmental)
4.	Short Term Availability	55	45	Long Term Availability
5.	Short Term Availability	50	50	Accessibility
6.	Long Term Availability	30	70	Accessibility
7.	Flammability	70	30	Degradability (Safety)
8.	Flammability	50	50	Toxicity
9.	Toxicity	70	30	Degradability (Safety)
10.	Short Term Sustainability	60	40	Long Term Sustainability

Criteria Result



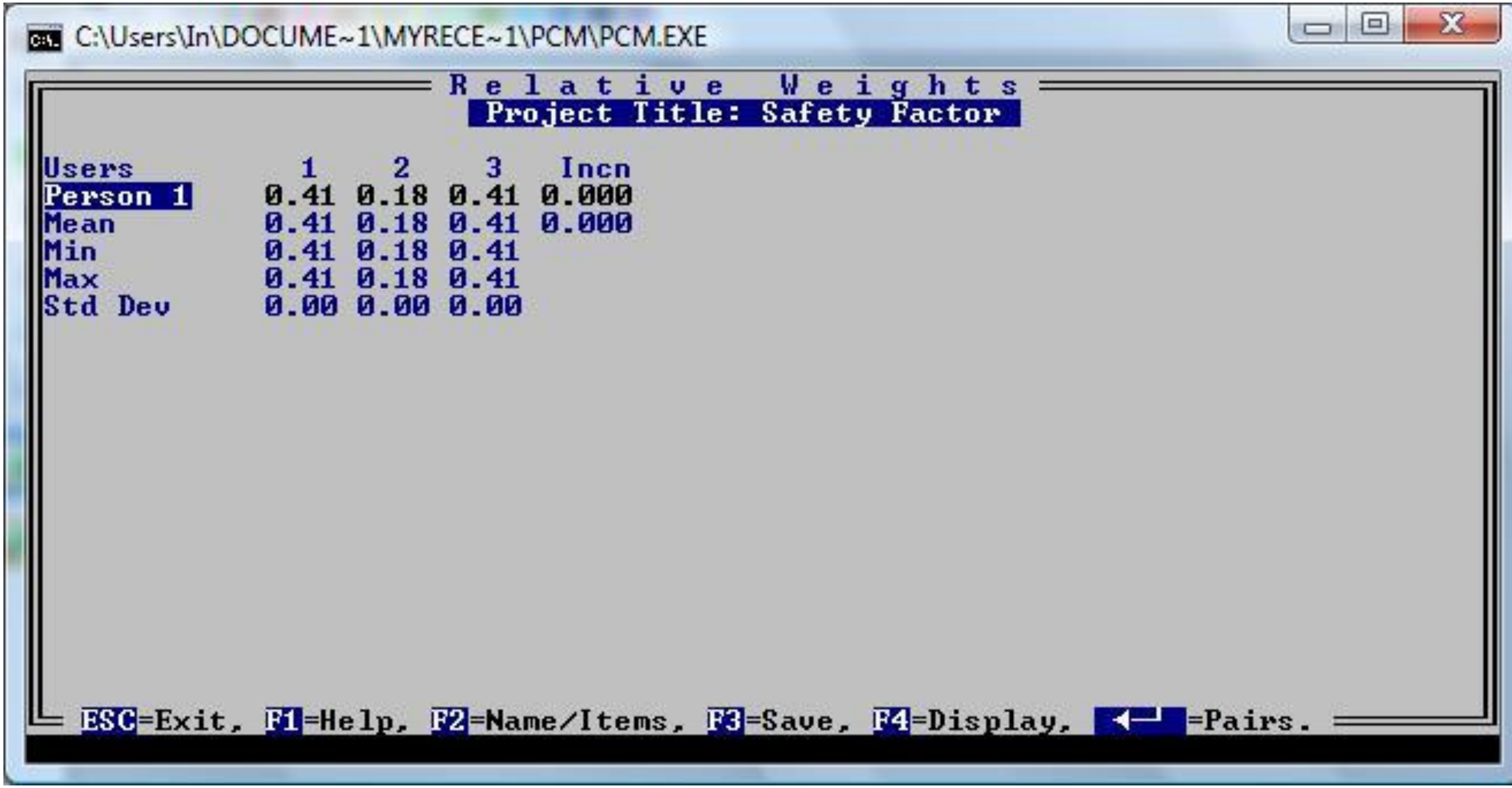
Result	0.31	0.10	0.29	0.19	0.11

Availability Result



Result	0.34	0.23	0.43

Safety Result



Result	0.41	0.18	0.41

Remaining Factors Result

- Cost Factor

	Implementation	Price per Unit (BTU)
Result	0.3	0.7

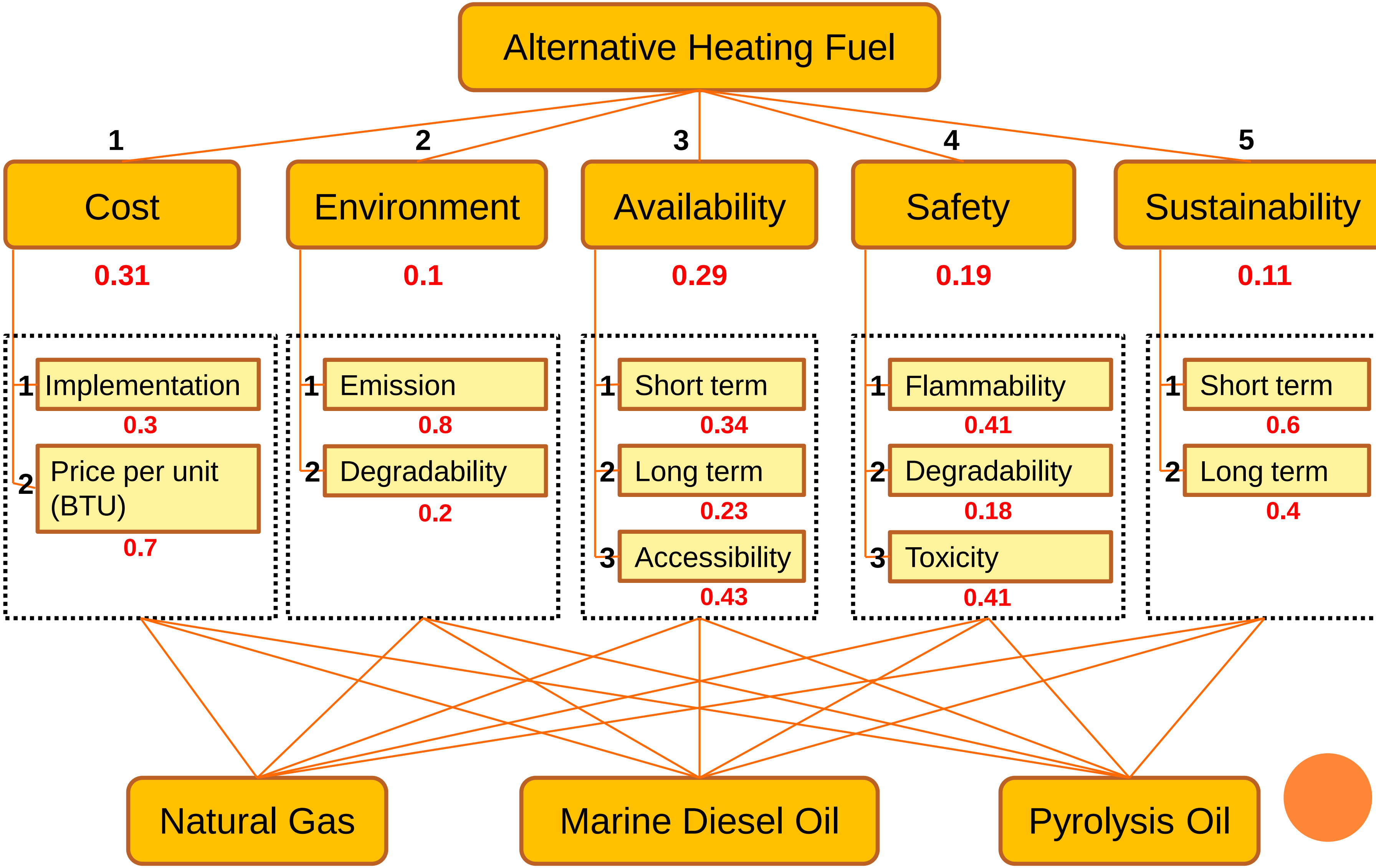
- Environment

	Emission	Degradability
Result	0.8	0.2

- Sustainability

	Short term	Long term
Result	0.6	0.4

Weight: Technology Assessment Model



Candidate Survey: Criteria

Candidate Comparison Survey

Participant's Name: ____________________

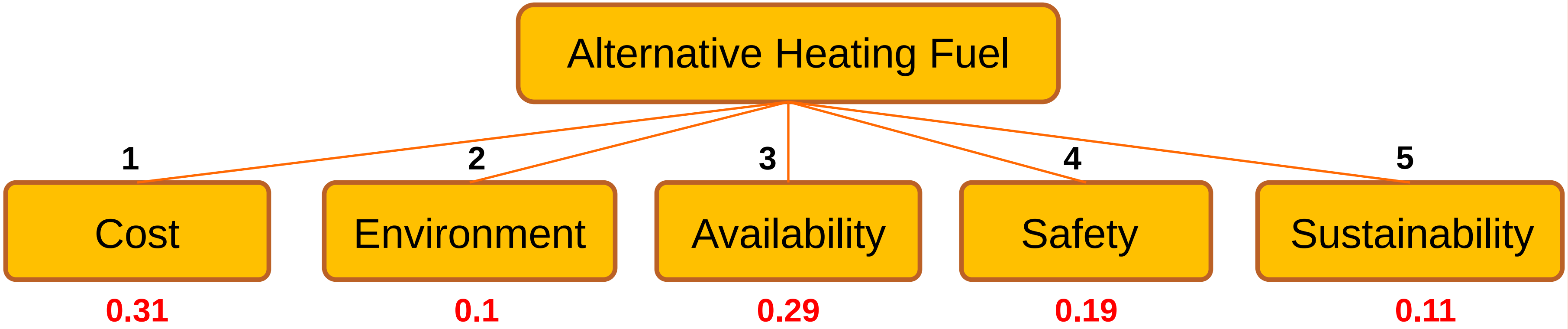
Affiliation: ____________________

*Please rate each of the three candidate technologies on a scale from 1 to 5, where 5 is **most** important and 1 is **least** important.*

Criteria Survey

	Criteria	Weight	Natural Gas	Marine Diesel	RedOx Pyrolysis Oil
1	Cost	.31	5	5	5
2	Environment	.1	4	2	2
3	Availability	.29	5	4	3
4	Safety	.19	4	3	4
5	Sustainability	.11	4	4	3

HDM: Result



Criteria	Natural Gas	MDO	Pyrolysis Oil
Cost	5 x 0.31 = 1.55	5 x 0.31 = 1.55	5 x 0.31 = 1.55
Environment	4 x 0.1 = 0.4	2 x 0.1 = 0.2	2 x 0.1 = 0.2
Availability	5 x 0.29 = 1.45	4 x 0.29 = 1.16	3 x 0.29 = 0.87
Safety	4 x 0.19 = 0.76	3 x 0.19 = 0.57	4 x 0.19 = 0.76
Sustainability	4 x 0.11 = 0.44	4 x 0.11 = 0.44	3 x 0.11 = 0.33
Total	4.6	3.92	3.71

Ex. Candidate Survey: Factors

Candidate Comparison Survey

Participant's Name: ____________________

Affiliation: ____________________

Please rate each of the three candidate technologies on a scale from 1 to 5, where 5 is ***most*** *important and 1 is* ***least*** *important.*

Factor Survey

	Factor	Weight	Natural Gas	Marine Diesel	RedOx Pyrolysis Oil
1	Implementation	.3			
2	Price per Unit (Mbtu)	.7			
3	Biodegradability (Environment)	.8			
	Emissions	.2			
4	Short Term Availability	.34			
5	Long Term Availability	.23			
6	Accessibility	.43			
7	Flammability	.41			
8	Degradability	.18			
	Toxicity	.41			
9	Short Term Sustainability	.6			
10	Long Term Sustainability	.4			

Conclusion

- Facilities departments are the decision makers for determining boiler-fuel types.

- The HDM Model and PWC models helps to evaluate technologies and assists the decision maker in identifying top concerns.

- In this model, candidate choice is based on relative weight of both **criteria** and **factors** describing the fuels.

- Major areas of concern were identified through literature review:
  - Cost
  - Environmental
  - Safety
  - Availability
  - Sustainability

Recommendation

- Future study is required. For proper decision to be made, data must be collected from PSU and other university campus facilities departments.

- In the case of RedOx, market research should be conducted using the HDM and PWC models, in the form of paper or online surveys.

- RedOx reactor has two values: **Pyrolysis oil production** and **Waste management**. Market research should also be conducted on customers of municipal waste management systems.
  - Responses that favor RedOx could be used to garner additional funding.
  - Data could be use to tailor product output to meet growing needs and concerns
- RedOx should partner with graduate studies in alternative energy, to collect market data, and *tune* **Criteria** and **Factors.**

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